AN EXPERIMENTAL INVESTIGATION INTO HOT MACHINING OF En-24 STEEL

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OFTECHNOLOGY

BY
ANAND PRAKASH CHAUDHARY

to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
JULY 1971

DEDICATED

TO

MY PARENTS

CERTIFICATE

This is to certify that this work on "An Experimental Investigation into Hot Machining of EN-24 Steel" has been carried out under my supervision and it has not been submitted elsewhere for a degree.

July 23, 1971

Dr. G.S.Kainth
Assistant Professor
Department of Mechanical Engineering
Indian Institute of Technology,Kanpur

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Anand Prakash Chaudhary

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SYNOPSIS

An experimental set-up has been designed, fabricated and installed for the study of hot machining of high strength materials during turning operation. Electric resistance heating method is used to heat the workpiece by passing single phase alternating current upto 600 amperes at 5 volts through an insulated tool. A review of the literature is given.

Cutting forces are measured by three dimensional lathe-tool dynamometer and recorded on two Sanborn dual-channel carrier-amplifier-recorders during conventional and hot machining of EN-24 steel using throw-away carbide tipped tools.

Tests are carried out to observe the effect of heating current on cutting forces at feeds, varying from 0.05 to 0.3 millimeter/revolution and at speeds varying from 10 to 55 surface meters/minute while the heating current is varied from zero to 300 amperes.

Results are interpreted and discussed. Finally conclusions are drawn and suggestions for further work are made.

CHAPTER I

INTRODUCTION AND LITERATURE SURVEY

1.1 General:

At present more effective machining methods are urgently needed to handle the machining problems of high strength, heat resistant alloys (Table 1) used in gas turbines, modern aircrafts, missiles and rockets for better, faster and economical machining.

Experience has shown[1] that these materials are either unmachinable or difficult to machine at room temperature. Conventional machining of these materials requires very low cutting speeds and feeds, with a correspondingly heavier load on machine bearings and slides. These materials undergo workhardening due to the plastic deformation that occurs in machining and attain tensile strengths close to those of the cutting tools used to machine them. Furthermore, extremely high cutting forces give rise to chatter vibrations, tool breakage, poor tool life and very low metal removal rate.

It follows that machining of these materials is of wide interest to production engineers, and 'HOT MACHINING' appears to provide one of the most promising lines of approach.

Chemical Composition %	AISI 4340	TIMKEN 16-25-6	S 816	IncondX	ThermoldJ	17-4-MO	17-7-PH
Carbon	0.43	0.08-0.10	0.4	0.08Max.	0.5	0.10	0.07
Manganese	-	2.0 Max.	1.0	0.3-1.0	0.4	-	0.65
Silcon	-	1.0 Max.	0.4	0.5 Max.	1.1	-	0.5
Chromium	0.8	16.0	19.8	14.0-16.0	5.0	17.0	17.0
Nickel	1.8	25.0	20.2	70 Min.	1.5	4.0	7.0
Molybdenum	0.25	6.0	4.3	-	1.4	3.0	-
Aluminium	-	-	-	0.4-1.0	-	-	1.0
Iran	96.72	Balance	3.5	5.0-9.0	89.1	75.75	73.7
Titanium	-	-	-	2.25-2.75	-	-	-
Tungsten	-	-	4.3	-	-	-	-
Columbium	-	-	3.8	0.70-1.25	-	-	-
Cobalt	-	-	42.3	-	-	-	-
Vanadium	-	-	-	-	1.0	-	-
Copper	-	-	-	0.2	-	-	-
Sulphur	-	-	-	0.01	-	-	-
Nitrogen	-	0.15	-	-	-	0.15	-
Yield Strength PSI							
at 68 F	180,000	95,000	-	-	250,000	180,000	200,000
at 500 F	170,000	81,000	-	-	240,000	180,000	170,000
at 1000 F	110,000	65,000	-	-	180,000	110,000	130,000
Brinell Hardness	3900R600	266	282	203	3900r600	380	390

TABLE 1: COMPOSITION AND PROPERTIES OF SOME MATERIALS USED IN "HOT-MACHINING" STUDIES (BREWER[16])

1.2 Principle and Function of Hot Machining:

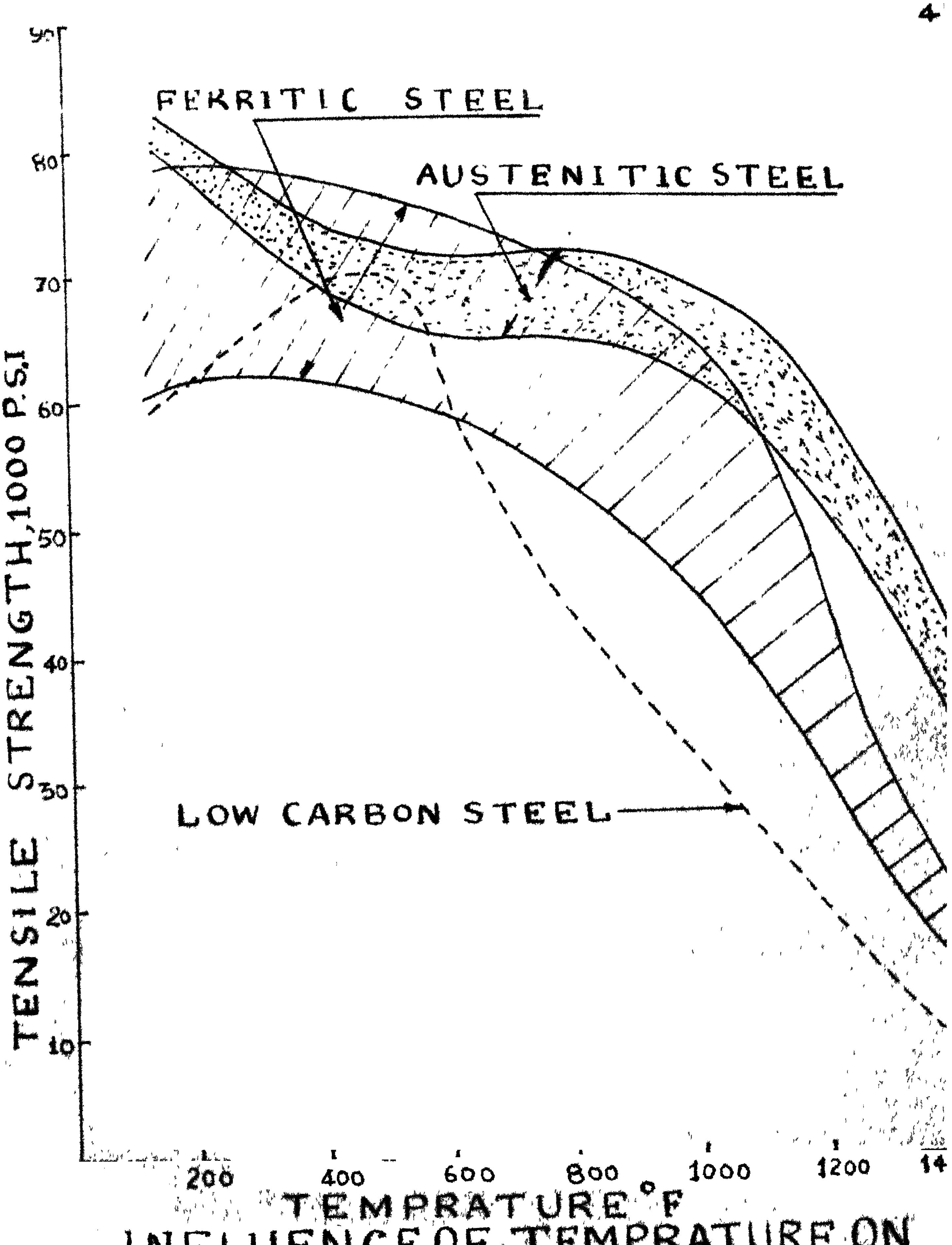
In usual machining process, it is modern practice to throw large quantity of coolant on the tool to reduce the friction and cool the tool. However, the workpiece is also cooled, with the result that the shear strength of the material remains high and it becomes more difficult to deform the material.

The very concept of hot machining runs contrary to conventional metal cutting practice. The basic idea behind hot machining is to raise the temperature of the workpiece close to or slightly above the recrystalization temperature in the vicinity of the shear zone. This reduces the tendency of strain hardening. The shear strength of the material is reduced with increase in temperature. Figure 1 shows the tensile strength of various steels at different temperatures[2]. In hot machining, shear strength of the material is reduced by heating the workpiece in the shear zone. Thus cutting forces are reduced and the machining can be carried out satisfactorily.

Hot machining has two main advantages:

(a) It is possible to machine components which would other ise necessitate some other expensive manufacturing process.

(b) It improves the production rate and machining economics of materials which could normally be machined at very low speeds and short tool life.



INFLUENCE OF TEMPRATURE ON TENSILE STRENGTH (SAMTOUR[2])

FIGURE NO1

Several methods of heating the workpiece have been developed and employed in investigations[3-7] of hot machining. These methods include: furnace, flame, radient, induction coil, radio frequency, electric arc and resistance heating.

1.3 Literature Survey:

Hot machining was put into practical use as early as 1941 to saw hot billets of steel at Krupp's Steel Works in Germany. There are reports[4,8] of research carried out in Japan during World War II. During 1941 to 51 several investigations were done[2-4,9-11], particularly in U.S.A. The increasing use of high strength, high temperature refractory materials led to several recent investigations[12-15] on hot machining.

Almost all the investigations so far carried out on hot machining can be classified into three main categories, viz. (i) Mechanics of cutting during hot machining, (ii) Hot machining tool life and tool wear and (iii) Hot machining tool temperature.

Table 1 gives[16] the composition and properties of some of the materials which are unmachinable or difficult to machine at room temperature. Change in mechanical properties of workpiece during hot machining, such as tensile strength[2], hardness of the tool and workpiece, percentage elongation[17], shear strength in

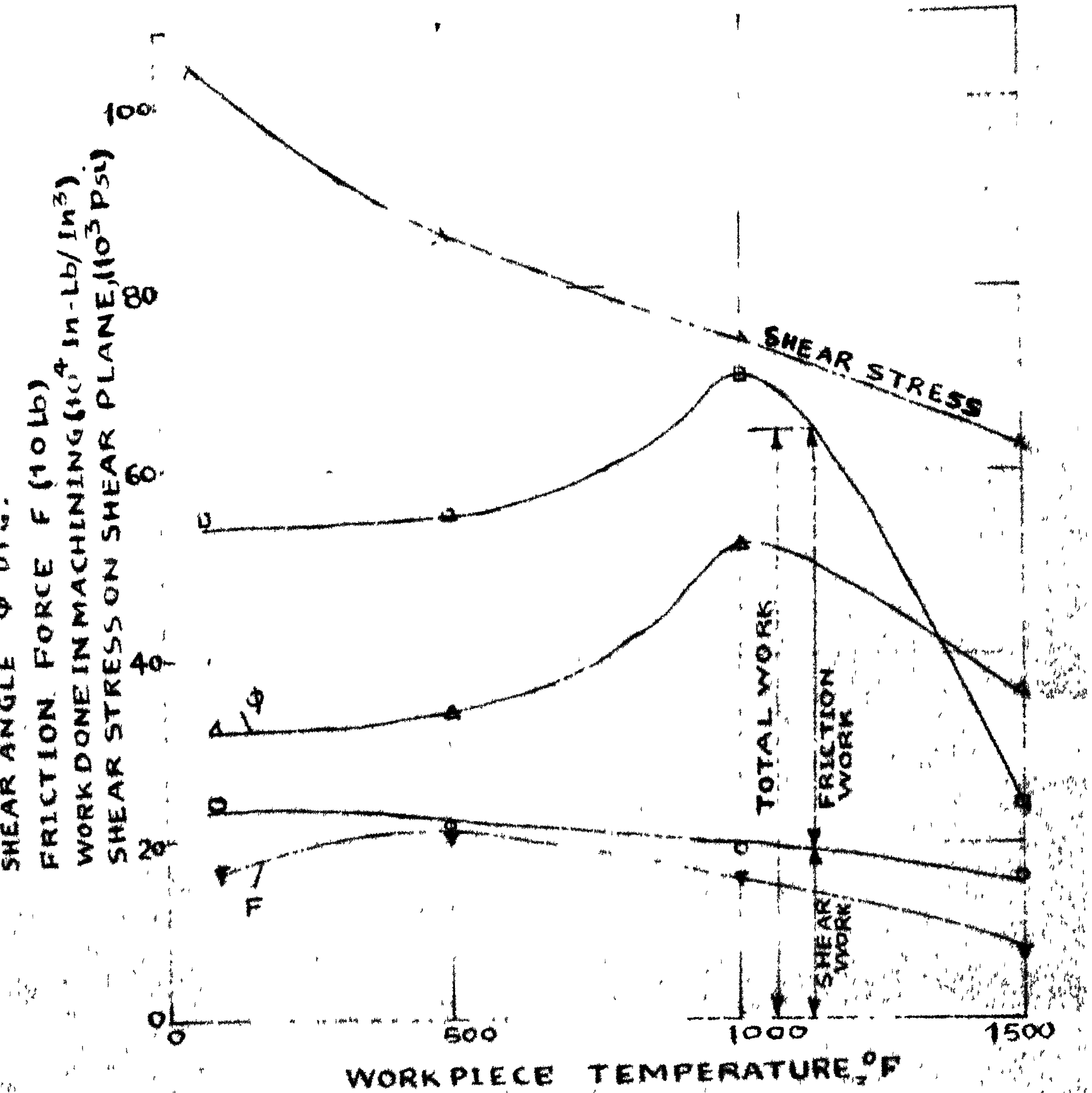
the shear zone[16] and chip material[10,12] adjacent to rake face, have been described by various investigators. Krabacher and Merchant[10] established experimental relationships between various cutting parameters and workpiece temperature as shown in Figure 2.

Charles[5] showed that 'with increase in workpiece temperature, the characteristic of the chip changes from semi-segmental strip to a smooth ribbon. These chips are separated from the workpiece with lesser vibrations and shocks to the cutting tool as compared to chips produced in conventional machining'.

Metal removal rate[2,5,7] increases many times during hot machining for equal torque load and at equal tool life. Barrow[7] claims an increase in the metal removal rate to 200 percent for a given tool life, as shown in Figure 3.

With electric current heating, workpiece is tempered to a depth approximately 0.15 inch[18] below the hot machined surface. This tempering is not severe and penetration is much less than in the case of other methods of heating. Figure 4 illustrates[18] the effect of hot machining on hardness of workpiece.

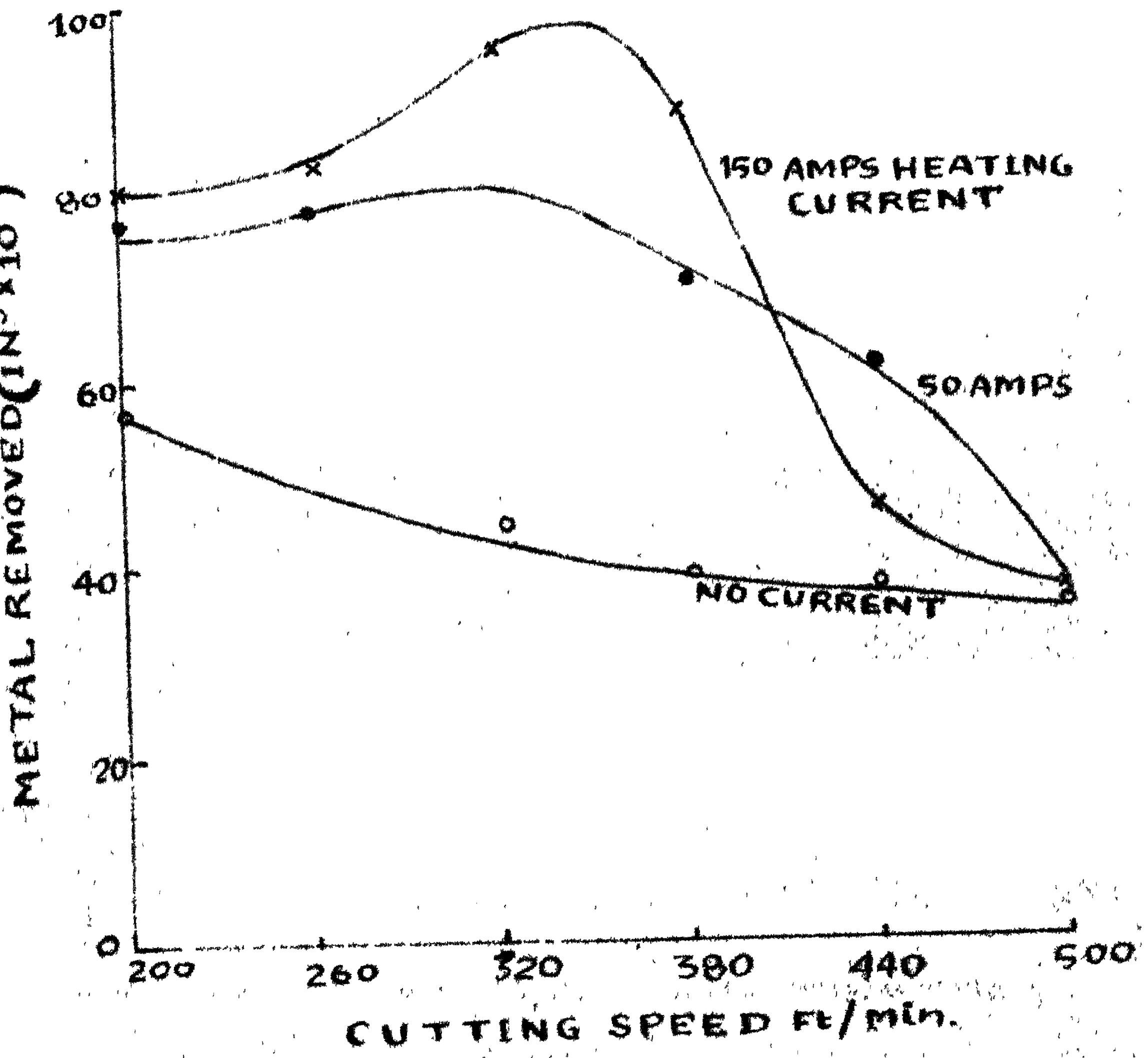
Microstructure and metallurgical examination of the workpiece during hot machining have been reported in various papers[5,7,9]. ~~There is~~ No detectable change[7]



RELATION BETWEEN VARIOUS FACTORS AND WORKPIECE TEMPERATURE DURING MACHINING (BREWER[16])

FIGURE NO 2

DEPTH OF CUT 0.08 IN.
FEED 0.012 IN/REV.
TOOL GEOMETRY 0, 6, 5, 5, 15, 15, 5/64
CARBIDE GRADE LENCHS ES
ALTERNATING CURRENT

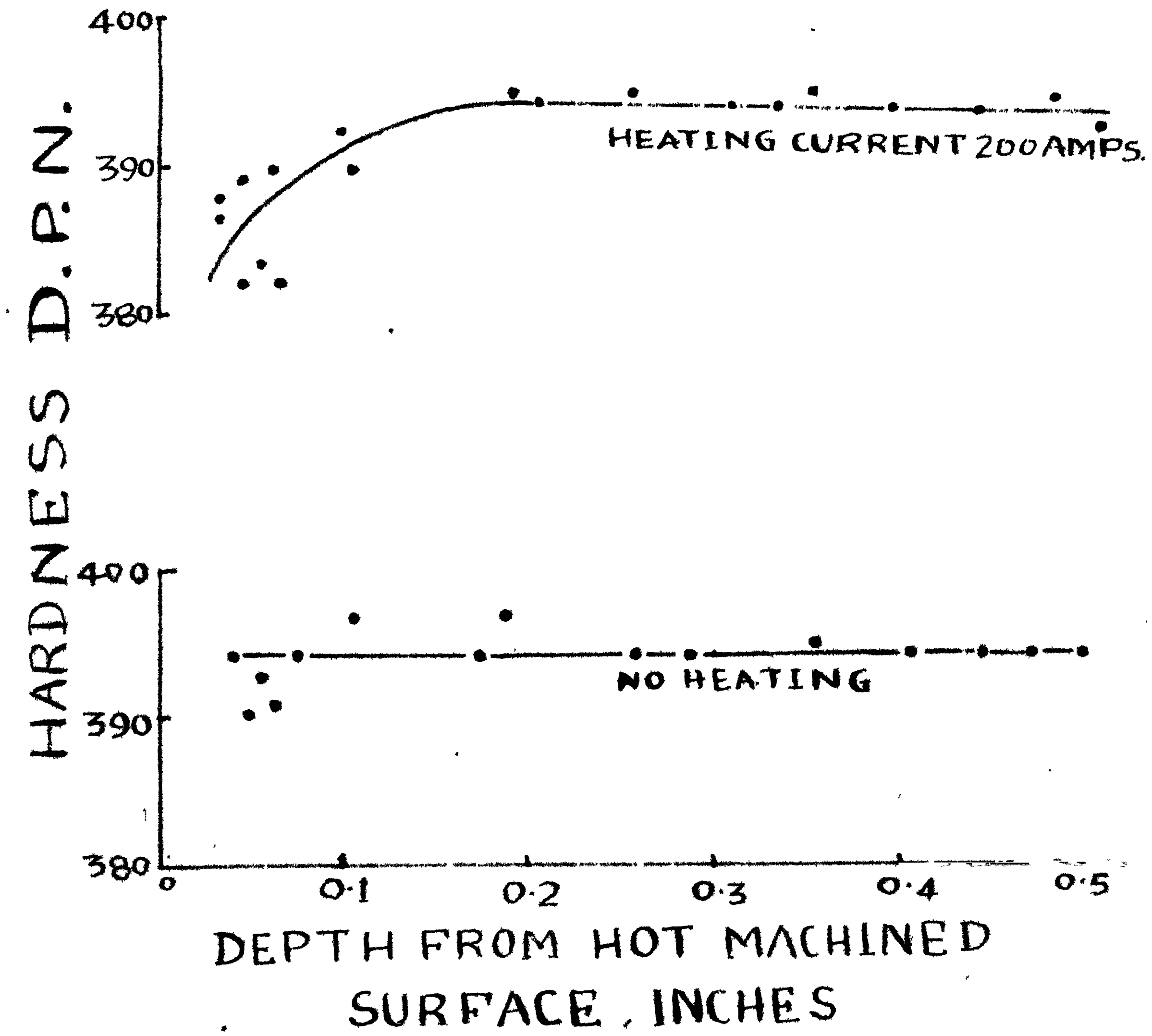


AMOUNT OF METAL REMOVED TO 0.010 IN. FLANK WEAR AGAINST CUTTING SPEED FOR EN 23 STEEL, U.T.S. 59 TON/ IN^2, B.H.N. 298 (BARROW[7])

FIGURE NO 3

WORK MATERIAL - EN 26, U.T.S 80 TON/IN^2
TOOL MATERIAL - CARBIDE
6° RAKE

CUTTING SPEED - 250 S.F.P.M
DEPTH OF CUT - 0·050 IN
FEED - 0·010 IN/REV.



EFFECT OF HOT MACHINING ON HARDNESS OF EN 26 (BARROW[18])

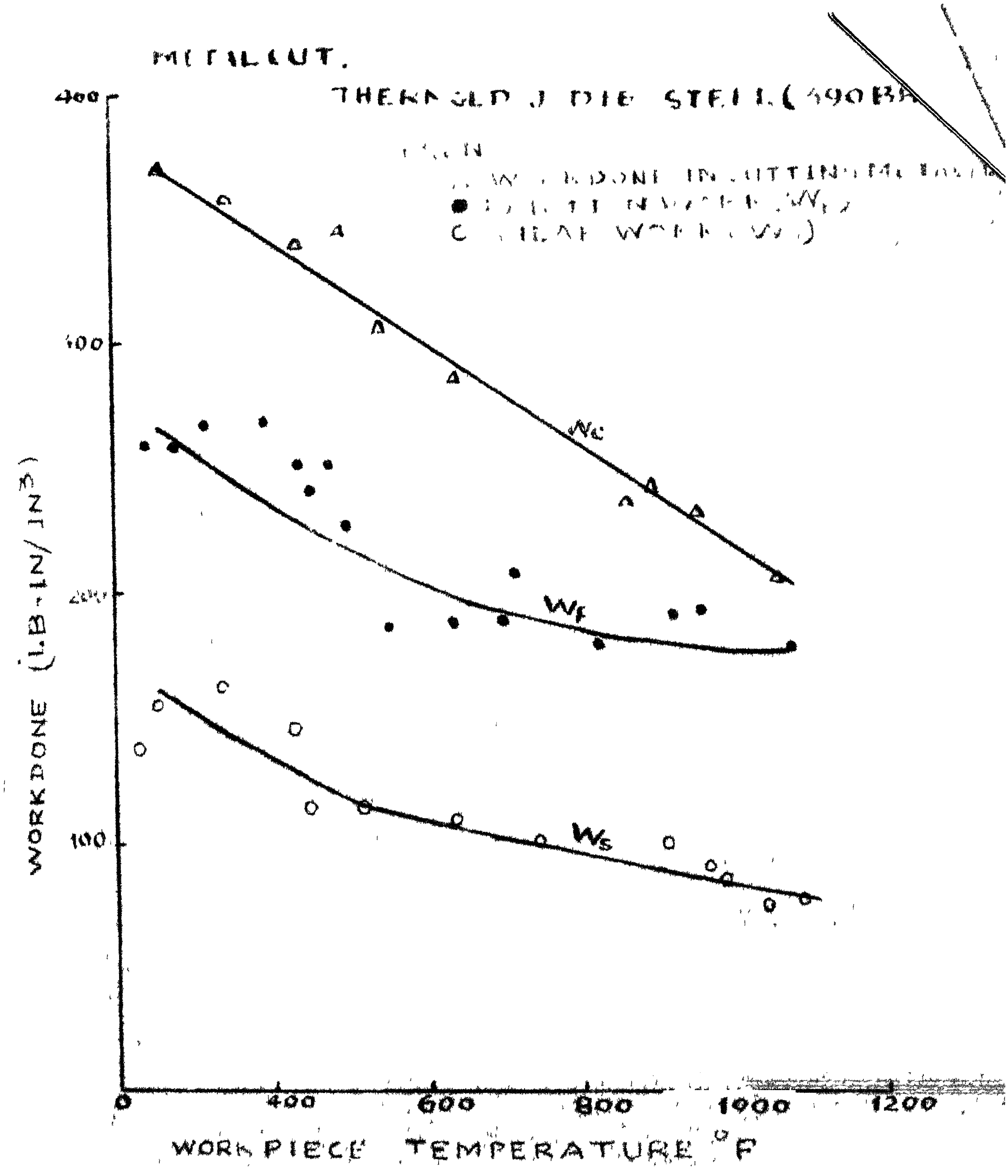
FIGURE NO 4

found in microstructure of hot machined workpiece. Work of Pentland, Wennberg and Mehl[5] shows that friction work and shear work both decrease with increase of workpiece temperature as shown in Figure 5.

Tour[2] and Barrow[18] found that the surface finish of hot turned workpiece is better than the finish obtained on the cold turned jobs under similar cutting conditions. The reasons for superior finish[18] are (i) chip becomes more ductile and its curvature decreases, (ii) tool vibration and chatter are reduced and (iii) built-up-edge disappears as the electric current reaches a certain value[8].

Tool life and tool wear in hot machining have been discussed in various papers[7,10,19,20]. For optimum tool life, the selection of feeds and speeds is critical[7]. Barrow[18] found an optimum value of heating current for maximum tool life. While cutting En-23 steel at a speed of 350 feet/minute, any heating current betwen 75 to 175 amperes would result in an increase in tool life at least 200 percent (see Figure 6).

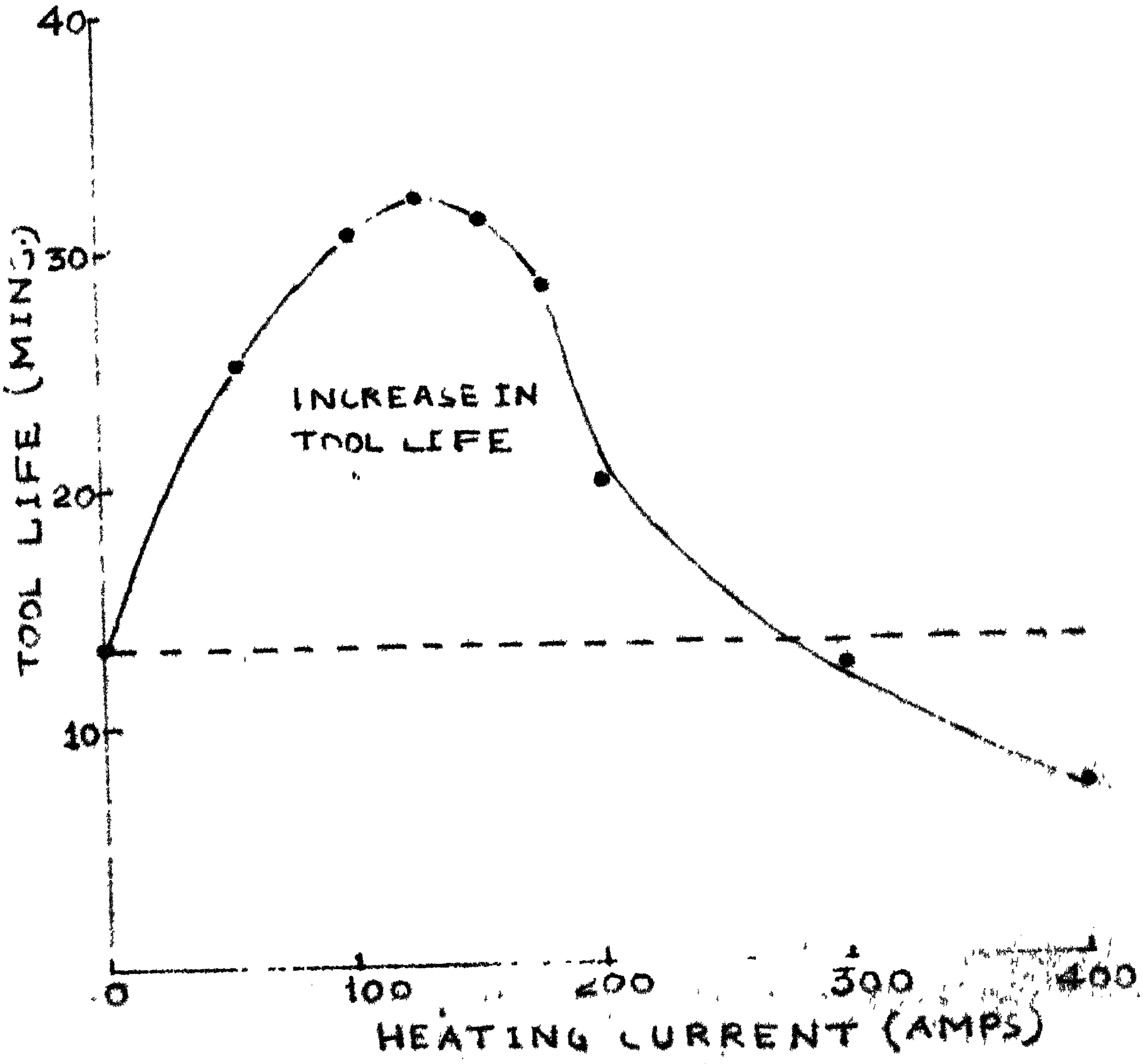
Various investigators[4,5,18] discussed the effect of heating current on chip tool interface temperature. Barrow[8] found the mean chip tool interface temperature increases with increase in heating current (Figure 7) and cutting speed (Figure 8).



INFLUENCE OF WOKEPIECE TEMP. ON WOKEDONE DURING MACHINING (PENTLAND, WENNBERG AND MEHL[5])

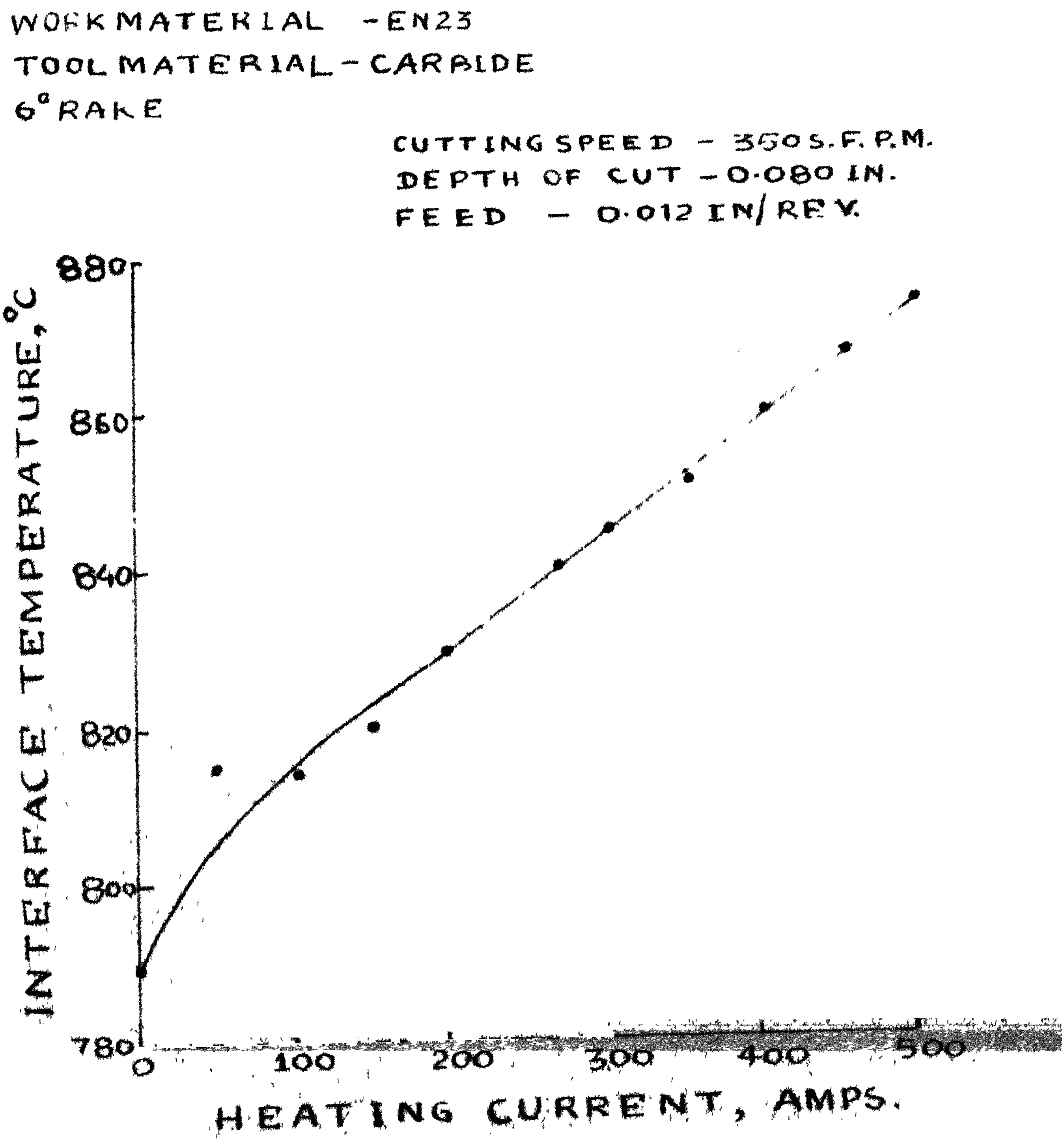
FIGURE NO 5

WORK MATERIAL - EN
TOOL MATERIAL - CARBIDE
6° RAKE
CUTTING SPEED - 350 S.F.P.M
DEPTH OF CUT - 0.080 IN
FEED - 0.012 IN/REV.



EFFECT OF HEATING CURRENT ON TOOL LIFE (BARROW[16])

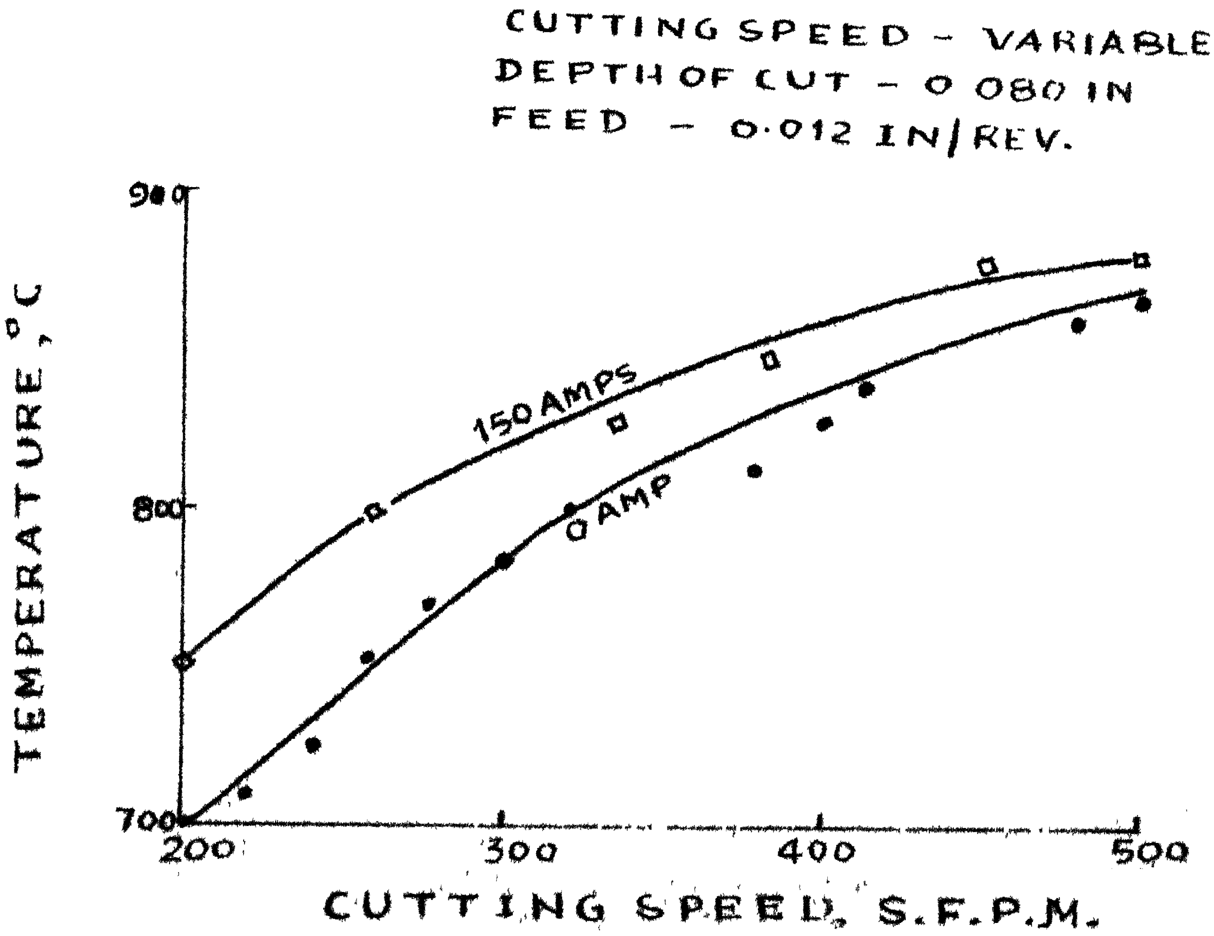
FIGURE NO 6



EFFECT OF HEATING CURRENT ON CHIP - TOOL INTERFACE TEMP. (BARROW[18])

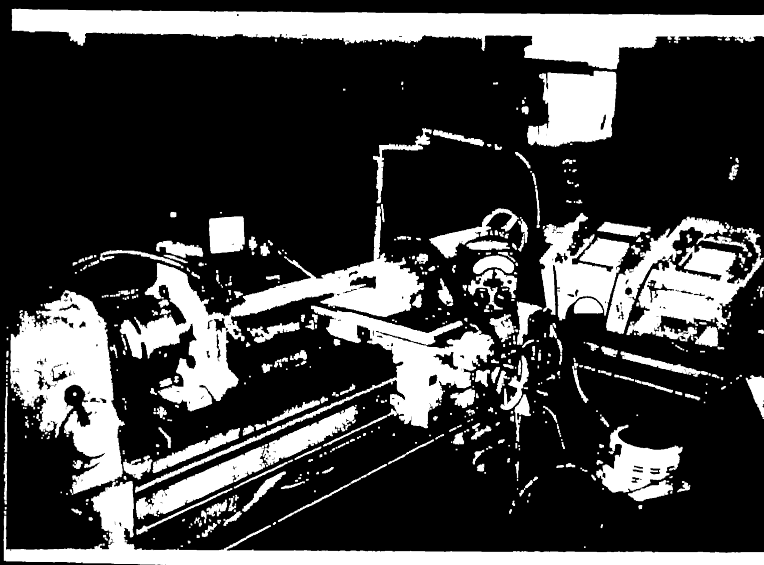
FIGURE NO. 7

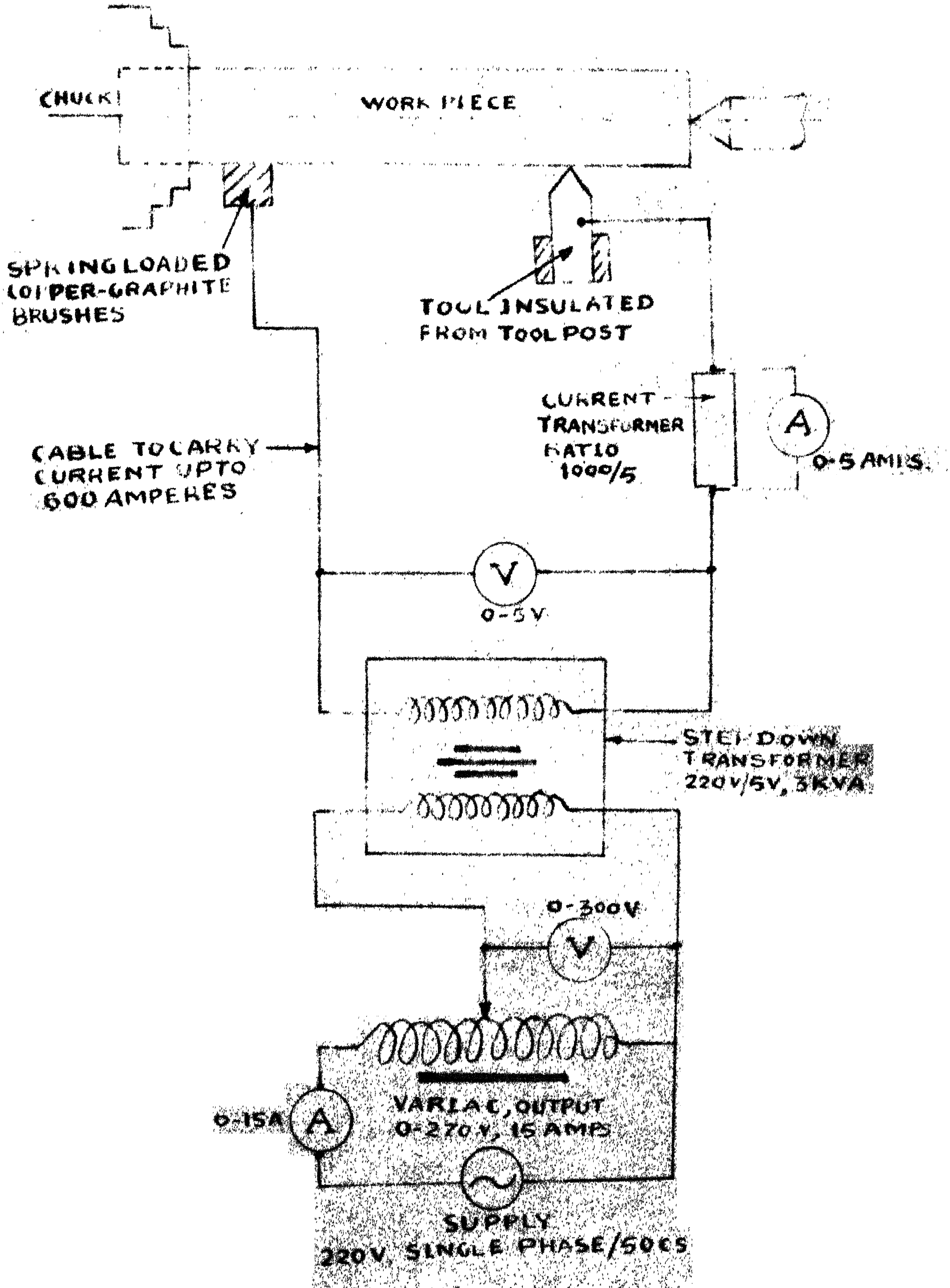
WORK MATERIAL - EN 23
TOOL MATERIAL - CARBIDE
6° RAKE



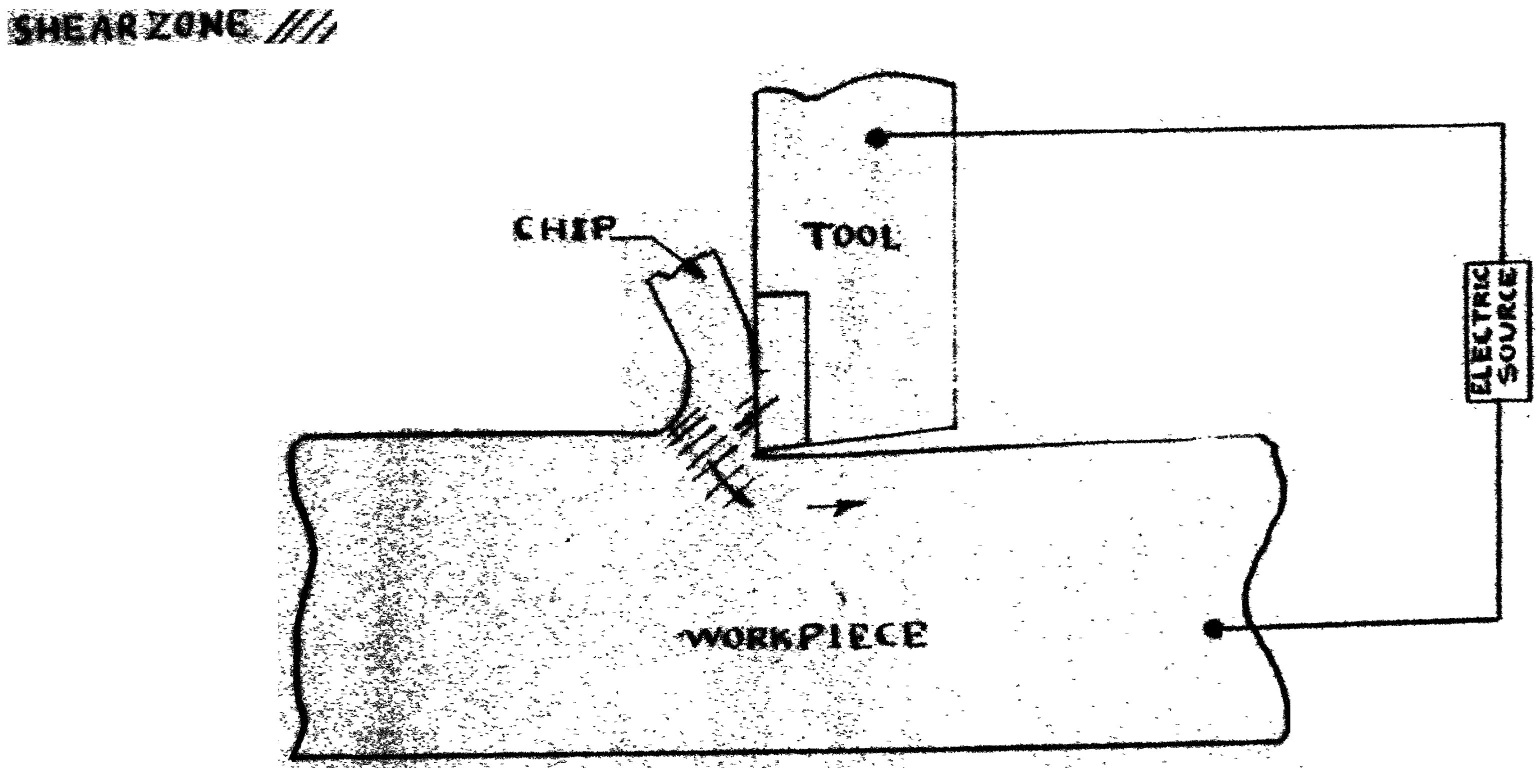
EFFECT OF HEATING CURRENT ON CHIP- TOOL INTERFACE TEMP. AT VARIOUS (BARROW[18]) SPEEDS

FIGURE NO 8





ELECTRIC CIRCUIT FOR "HOT MACHINING"
FIGURE NO 10



PRINCIPLE OF HOT MACHINING BY ELECTRIC CURRENT (RESISTANCE HEATING)

FIGURE NO 12

the tool-workpiece interface. This minimum area of cross section offers a high resistance to the current in the circuit. Enormous heat, equal to V^2/R, is produced at this area which is in the vicinity of the shear zone where the plastic deformation of the workpiece takes place.

The block circuit diagram for hot machining is shown in Figure 10. A high alternating electric current of 600 amperes at 5 volts passes through the tool. The tool is insulated from the machine by 1/8" thick asbestos sheet, placed between tool and dynamometer. Asbestos, being a bad conductor of heat, does not allow heat to flow towards strain gages, thus preventing the strain gages from being damaged.

Cables, having 600 amperes current carrying capacity, are used to pass the current through the tool and the workpiece. Current is supplied to the heating system through a step-down (220V/5V) transformer. To get a varying heating effect at the chip tool interface, the input voltage to the step down transformer is varied through a variac. A current transformer is used in the circuit to enable high current measurement.

Spring loaded copper-graphite brushes are used to ensure the proper electrical contact between the workpiece and the brushes.

The heating system is relatively easier to install and operate. It is suitable for workshop conditions and cleaner as compared to other heating systems. As electrical resistance of the workpiece is very low, high voltage is not required. This heating method offers no danger to operator since it is operated at low voltage.

The limitations of the method are as follows:

(i) It can be used only for the tool tips which are made of electrically conductive materials.

(ii) The current flow causes sparking across the gap at the time of the engagement and disengagement of the tool from the workpiece and consequently damages the clearance face of the tool.

The latter limitation can be reduced or even completely eliminated by judicious instrumentation[18], such as relay and cut-off switches to provide another electric path to the current at the time of engaging and disengaging the tool from the workpiece.

2.3 Brush and Brush-Holder:

Brushes are employed to collect the current from a 75 mm diameter workpiece. These are made of copper-graphite metal mixture of 65% copper and 35% graphite, having a current density of 100 amperes/square inch[22]. These brushes have high thermal conductivity which permits them to operate at very high current density.

They have very low contact resistance, resulting in relatively low losses and satisfactory service.

Figure 13 shows an assembly drawing of brush, brush holder and bracket. Each brush-holder is associated with one bracket. Brackets are bolted to the steady-rest at 120 degree apart from each other.

The details of the brush-holder are illustrated in Figure 14. Three brush-holders,accommodating six brushes, have been designed and fitted to the steady-rest which is clamped on the lathe bed.

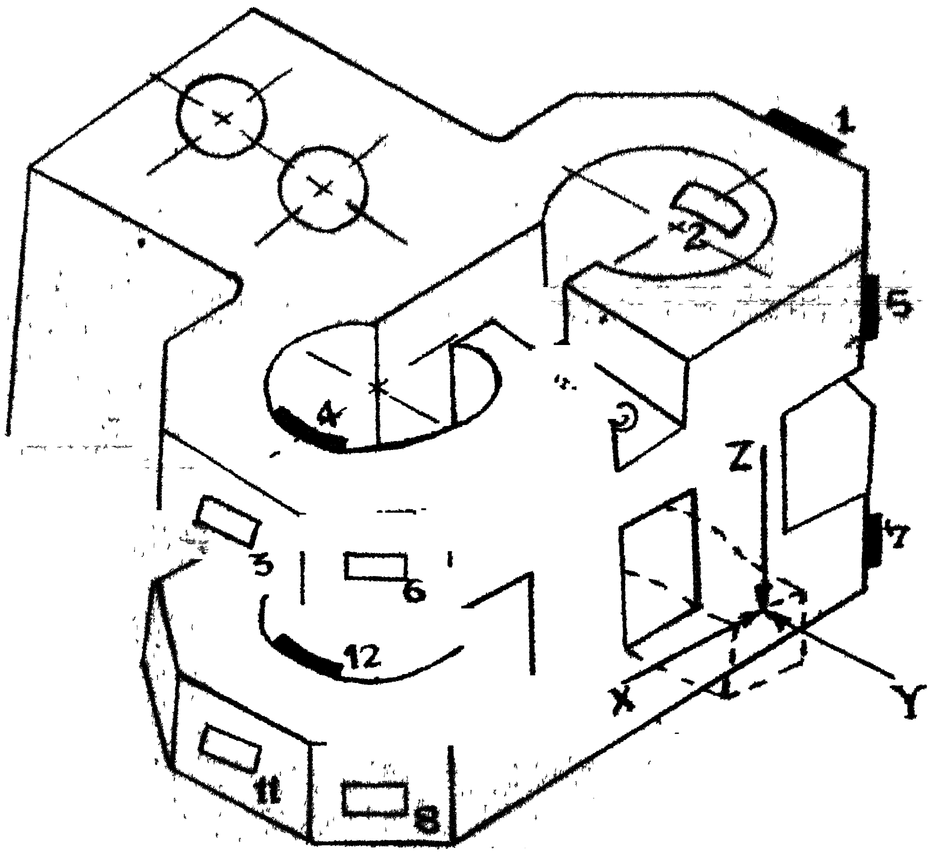
The details of the brush are shown in Figure 15. Six spring loaded radial brushes are fitted in the brush-holders and this facilitates the job to rotate in both clockwise and anticlockwise directions.

2.4 Three-Dimensional Lathe Tool Dynamometer:

A three-dimensional lathe tool dynamometer has been designed[23,24,25] for loads of 200 Kgs., 100 Kgs. and 400 Kgs. in X, Y and Z directions respectively (Figure 17). It is ensured that the strain remains within the elastic limit (1,000 micro-inch/inch) of the mild steel. The dynamometer consists of two extended octogonal rings one above the other as shown in Figure 16.

Twelve strain gages are cemented on the body of the dynomometer as illustrated in Figure 17. These are

X HORIZONTAL DIRECTION
Y AXIAL DIRECTION
Z VERTICAL DIRECTION
1 TO 12 STRAIN GAGES.
GAGES 9 & 10 ARE BELOW THE GAGES 1 & 2 RESPECTIVELY ON BOTTOM RING



3-COMPONENTS LATHE TOOL DYNAMOMETER

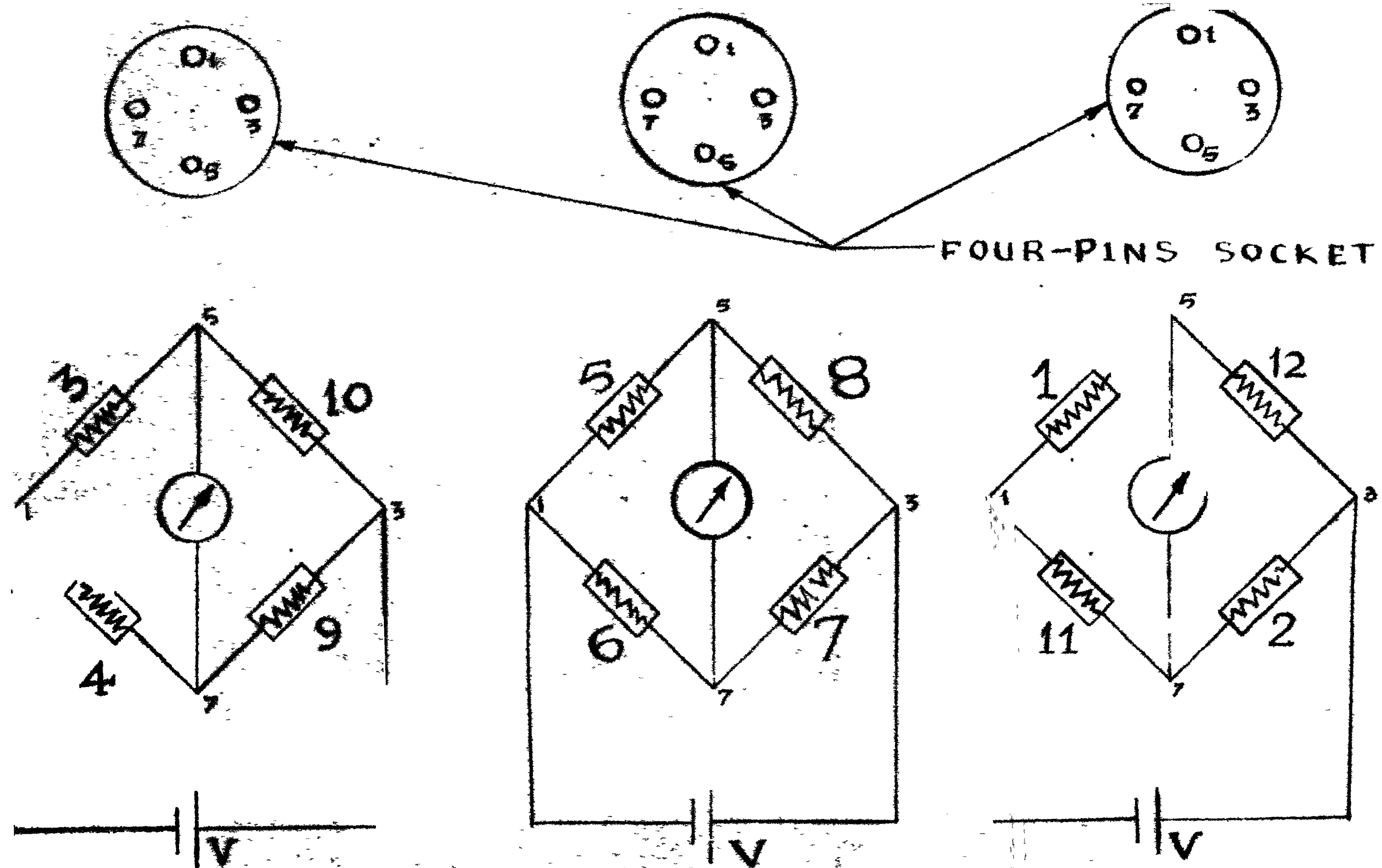
FIGURE NO 17

paper based strain gages having 117.3 ohms resistance and 2.82 gage factor. The gages are connected to form wheatstone bridge and to give minimum cross-sensitivity between the force components. The connections of the gages for measuring forces in three directions are shown in Figure 18. Force F_x is measured by gages 5, 6, 7 and 8, Force F_y by gages 3,4,9 and 10 and Force F_z by gages 1,2,11 and 12.

The dynamometer has been fabricated and enclosed in an aluminium box. Figure 10 shows the close-up view of the dynamometer. The dynamometer is bolted on the holding platform which is fixed on the lathe after removing the compound slide.

Before calibrating the dynamometer, it was used for cutting the metal for an hour. This way, the gages are cycled to the maximum future load level. This preloading minimises the zero shift and hysteresis errors as well as it gives an indication whether the gages have been properly cemented or not.

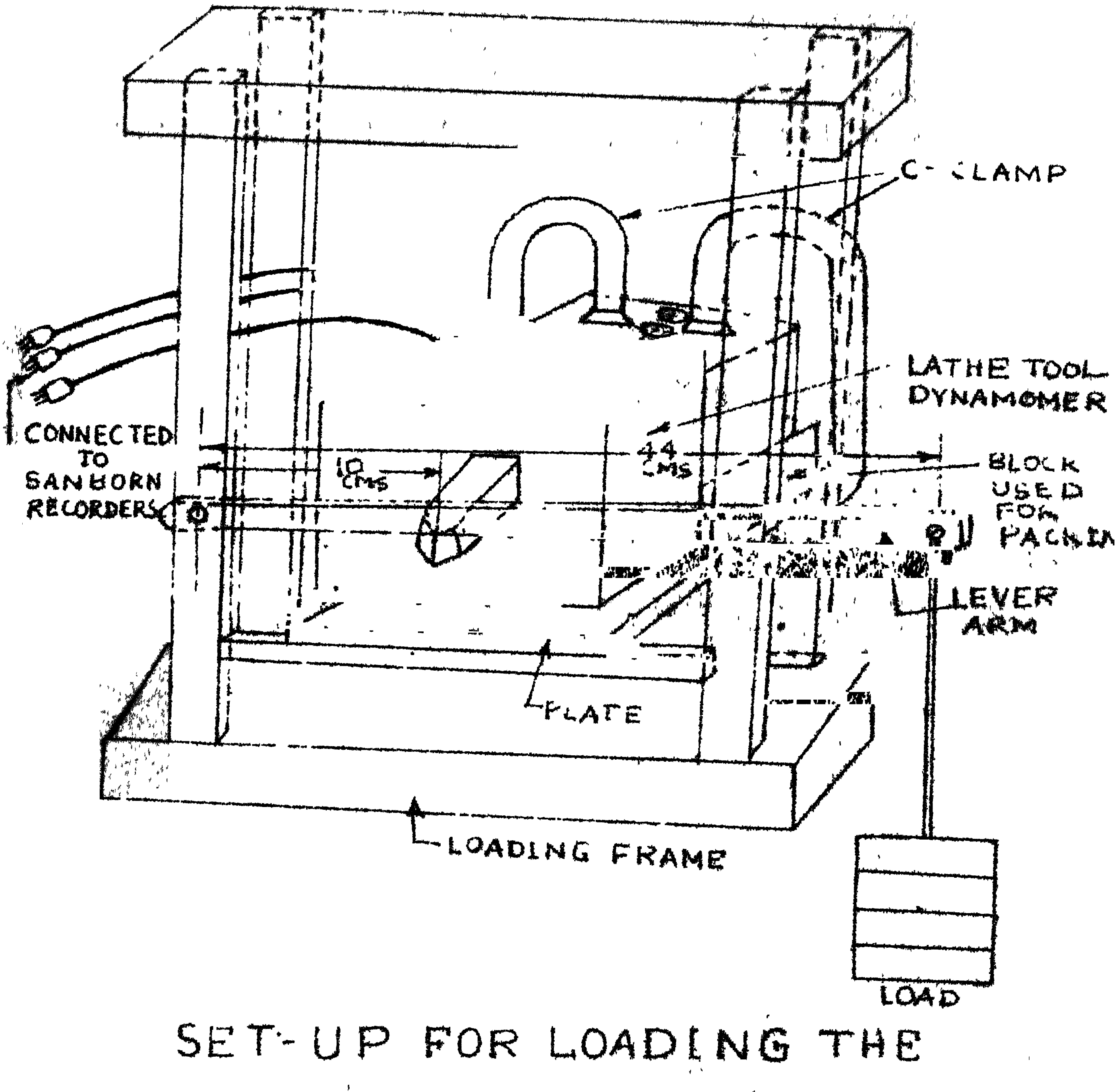
A loading frame with a lever arm radio adjusted to 4.4 was used for calibrating the dynamometer. The calibrations in three directions were carried out one by one by changing the position of the dynamometer itself. The set-up for loading the dynamometer for calibration is shown in Figure 19. Figure 20 shows



(A) CIRCUIT FOR F_Y (B) CIRCUIT FOR F_X (C) CIRCUIT FOR F_Z

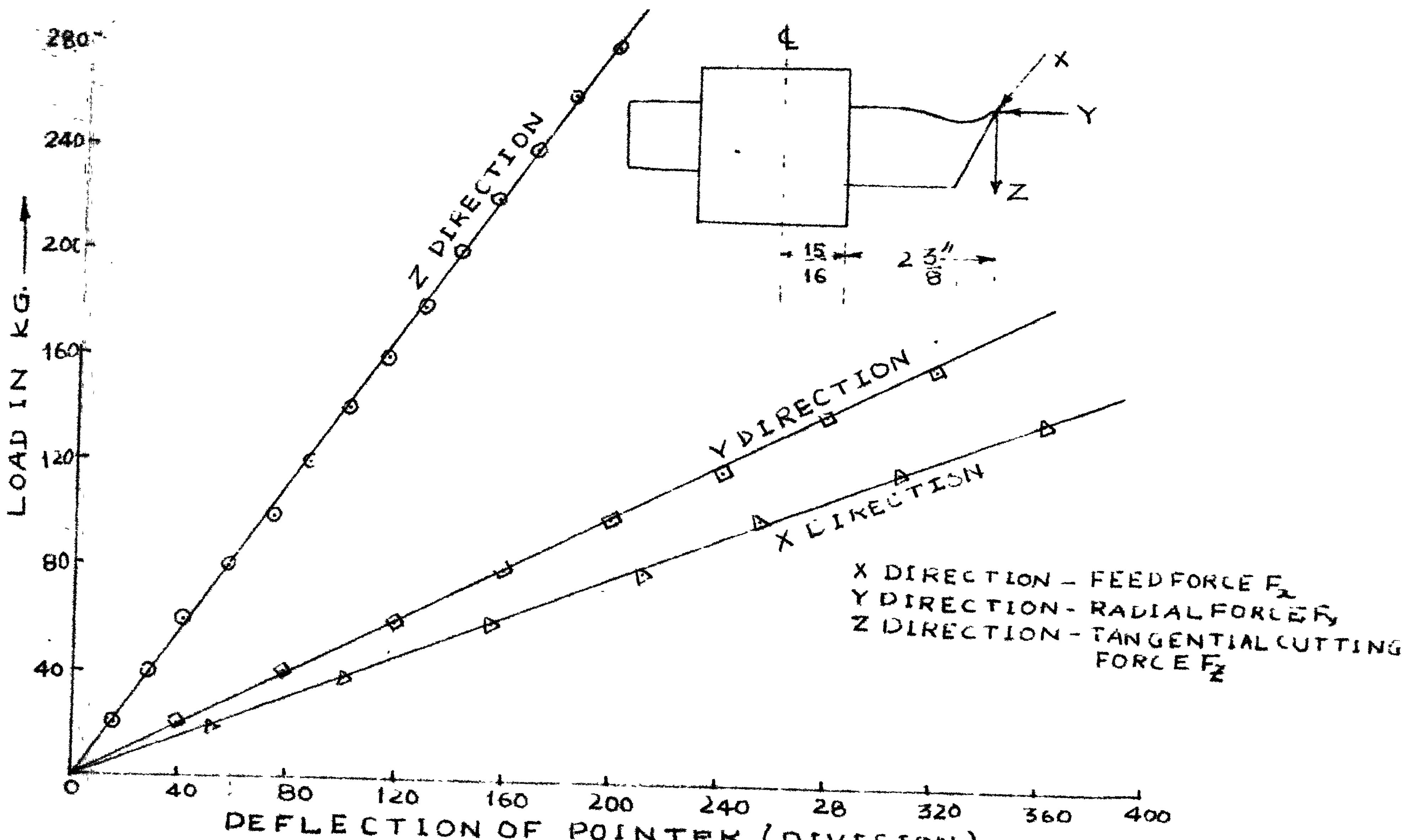
WHEATSTONE-BRIDGE CIRCUITS FOR MEASURING FORCES IN THREE DIRECTIONS

FIGURE NO 18



SET-UP FOR LOADING THE DYNAMOMETER FOR CALIBRATION

FIGURE NO 19



CALIBRATION CURVES FOR THREE DIMENSIONAL LATHE TOOL DYNAMOMETER

FIGURE NO 20

the calibration curves of the dynamometer. The dynamometer has a cross-sensitivity of approximately 2.5% in the three directions.

2.5 <u>Instrumentation</u>:

A step-down transformer is used to supply high alternating current upto 600 amperes at 5 volts. The specifications of the transformer are: 220V/5V, single phase, 50 c/s, 3 KVA rating and for continuous duty.

To get variable currents, input to the step-down transformer is varied through a continuously variable 'variac' having the following specifications: 220V, single phase, 50 c/s, having output 0 - 270 volts at 0 - 15 amperes.

A bar-primary-low-tension-type current transformer of current ratio 1000/5 is used. It facilitates the measurement of high alternating current with ordinary 0-5 amperes ammeter.

Two Sanborn dual channel carrier amplifier recorders are used to measure the strain produced due to cutting forces. Each channel has a high gain amplifier and operates with its external strain gage bridge. Inkless recordings are made by hot-wire-writing-arm on heat sensitive Sanborn permpaper recording chart.

CHAPTER III

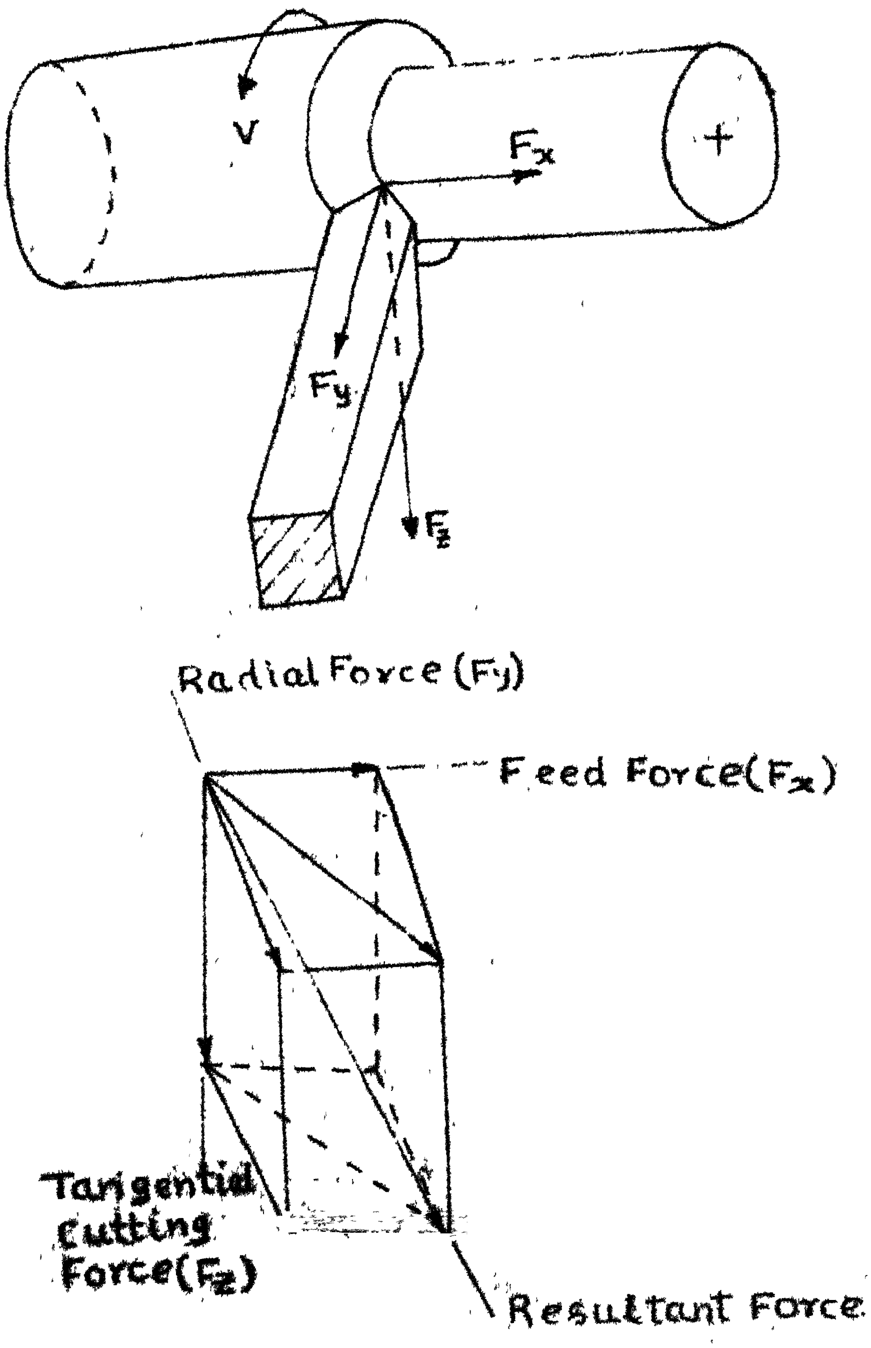
EXPERIMENTAL INVESTIGATION

3.1 General:

In the present investigation cutting forces were measured for conventional machining and hot machining processes over a wide range of cutting speeds and feeds.

Forces and power requirements in metal cutting operations are of importance in connection with the selection of a suitable motor for machine tools. The above information also wields considerable influence on the design of power transmission mechanism, determination of stresses and deflections in machine tool structures, and design of jigs and fixtures.

The force system encountered during a conventional turning process using a single point cutting tool is shown in Figure 21. The main cutting force F_z is tangential to the machined surface and perpendicular to the axis of turning. The force F_z and cutting speed V determine the power required for main spindle drive. The feed force F_x in a direction parallel to the axis of rotation and the feed rate determine the power requirement for lead screw drive. The force F_y perpendicular to the axis of the job and normal to the turned surface is called radial force.



THREE COMPONENTS OF FORCES ACTING ON A SINGLE - POINT CUTTING TOOL DURING CONVENTIONAL TURNING PROCESS

FIGURE NO 21

All the cutting tests were carried out on a 10 H.P., H.M.T. LB-17 lathe.

En-24 alloy steel (Appendix I) round bar of 51 millimeter diameter and one meter long was used as a test specimen. En-24 alloy steel was selected since its machinability is low (53% of mild steel[21]).

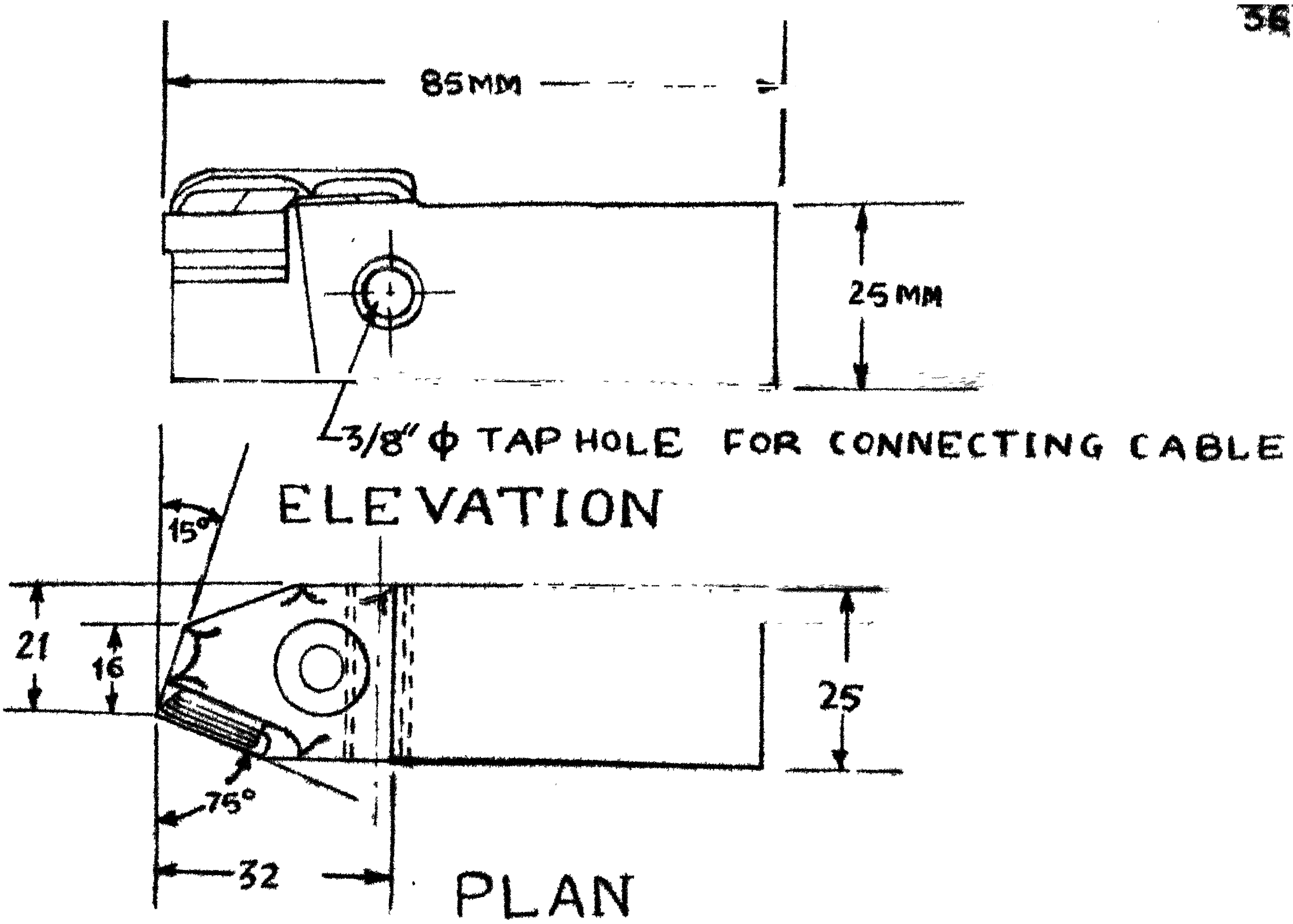
The details of the insert and tool shank are shown in Figure 22. Carbide tool tips were used during this investigation since it retains its hardness upto approximately 700°C. The tips are throw-away square inserts grade S4 and of zero degree rake angle. This tool is suitable for machining various kinds of steels even under unfavourable condition of high temperature. A standard chip breaker BC_1 of Sandvik make was used.

A travelling-steady was used just in front of the tool to provide rigidity to the workpiece.

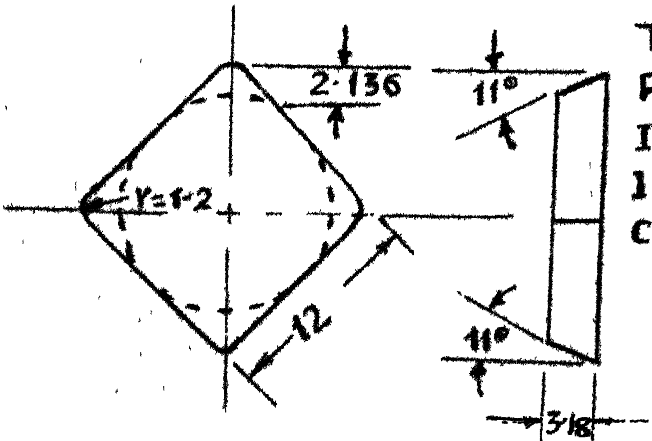
3.2 Experimental Procedure:

To obtain smooth contact surface between the workpiece and brushes, the workpiece was machined and ground at the contact position. Remaining portion of the test piece was machined for performing the tests.

Sanborn recorders were switched on for two hours for their maximum stability and then used for cutting force monitoring.



RIGHT-HAND TURNING TOOL



TOP RAKE	+6
FRONT TO BACK RAKE	0°
INSERT LENGTH	12
INSERT THICKNESS	3·18
CORNER RADIOUS	1·2

SQUARE TOOL TIP INSERT

DIMENSIONS IN MILIMETER

TOOL AND TOOL TIP INSERT

FIGURE NO 22

With a fresh cutting edge, a series of conventional machining tests were performed over 5 cms length of work-piece at a speed of 32 meters/minute and a depth of cut of 1 millimeter while varying the feed from 0.05 to 0.3 millimeter/revolution.

Chatter of the tool was the dominant difficulty experienced during investigation. It was present due to excessive overhang ($2\frac{5}{16}$ inch) and insufficient rigidity of the tool due to its insulation.

The tests were performed at the low cutting speed to reduce chatter vibration of the tool and to minimise the error due to tool wear.

For hot machining tests, the above procedure was followed at 50, 100, 150, 200, 250 and 300 amperes of current, keeping other cutting conditions unchanged. A new cutting edge was used for each current level to ensure similar tool condition during the tests. Tests could not be performed at currents greater than 300 amps. since the tool form was lost due to excessive flank wear.

The test specimen was again machined for subsequent tests. The above experiments were repeated by changing the feed in decreasing order from 0.3 to 0.05 millimeter/revolution. The tests with increasing and decreasing feeds were performed to decrease the effect of tool wear on the cutting forces.

Two sets of readings were taken for increasing and decreasing feeds. For each current setting and feed, the mean of the above four readings was found out to plot the cutting forces.

During the above four sets of tests, the same portion of the workpiece was used for a particular current level. This minimises the errors due to change, if any, in the hardness, microstructure or the properties of the workpiece due to heating in the previous test.

Further experiments were performed on the same lines but varying the cutting speed from 10, 15, 23, 33, 43 and 54 meters/minute. The depth of cut was maintained at 1 millimeter while the feed was kept at 0.15 millimeter/revolution. For the reasons mentioned earlier, above tests with increasing and decreasing speeds were carried out.

To avoid sparking at the time of engagement and disengagement of the tool from the workpiece, following procedure was adopted. (i) First the tool was engaged and the current was switched on. (ii) The switch was turned off before disengaging the tool.

At the end of each set of tests the dynamometer along with the tool were air cooled by a blower as a safe guard against the possible damage that might be caused to the strain gages on account of their heating. This cooling was provided at and above 200 amperes

current. Air cooling can be eliminated with the use of high temperature strain gages.

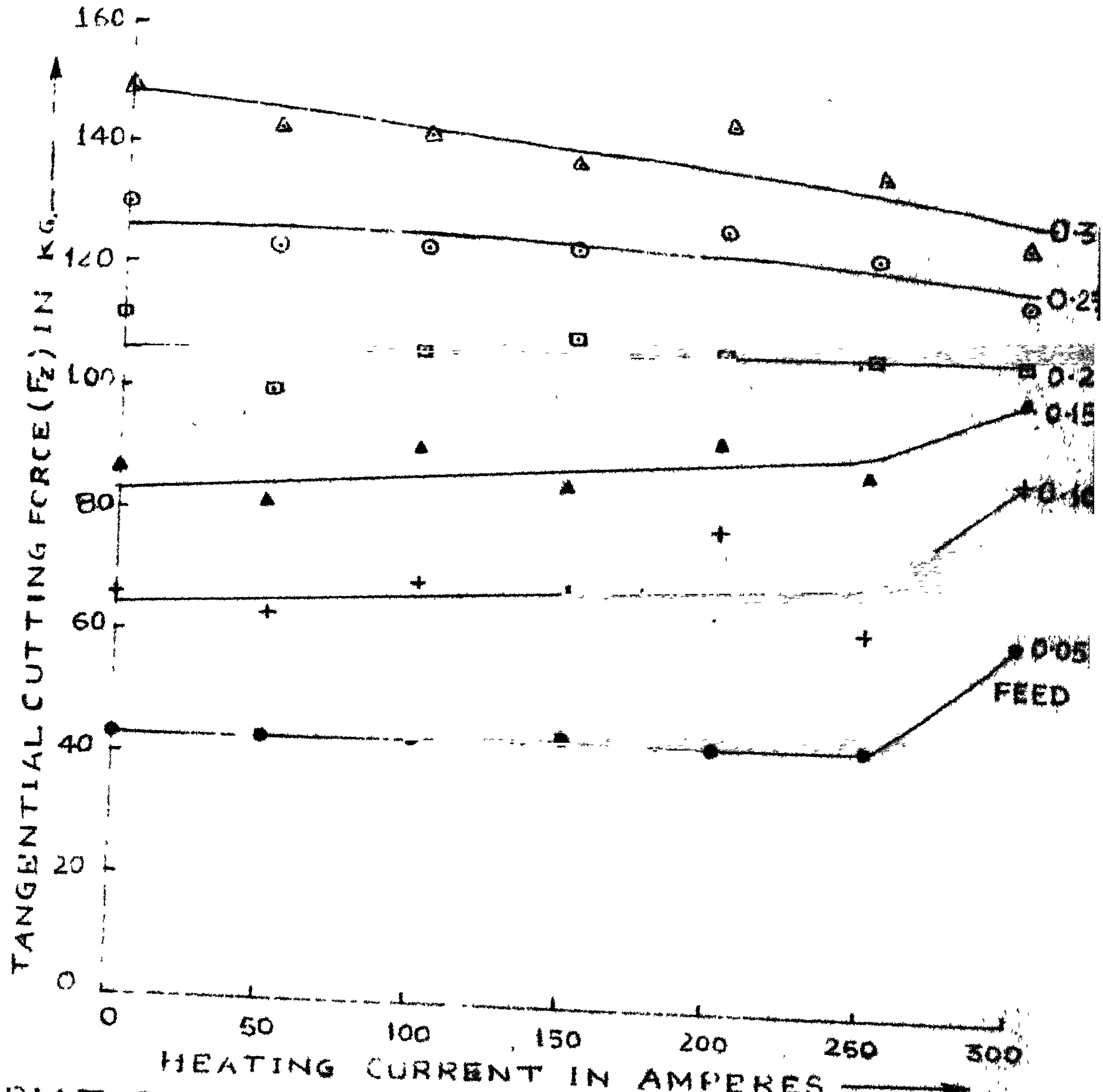
3.3 Results and Discussions:

The experimental results of the present investigation are plotted taking heating current along absissa and cutting forces along ordinate with feeds and speeds as variable parameters. These are shown in Figures 23 to 26. Photographs of the chips collected during the tests are shown in Figures 27.1 to 27.7. Figures 28.1 to 28.7 show the tool wear land for various heating currents from zero to 300 amperes at a cutting speed of 32 meters/minute.

3.3.1 Effect of Heating Current on Cutting Forces at Different Feeds:

The results plotted on Figure 23 show the effect of heating currents on tangential cutting force F_z, for various feeds. The force F_z is more or less constant for the feed of 0.05 millimeter/revolution with the increase in the heating current upto 250 amperes. As the feed increases from 0.05 to 0.15 millimeter/revolution the force F_z tends to increase with the increase in the heating current. There is a sharp change in the tangential cutting force F_z at 250 amperes with low feeds (less than or equal to 0.15 millimeter/revolution), followed by an appreciable increase at heating current of 300 amperes. This increase in the tangential cutting force F_z is due to the presence of the excessive flank

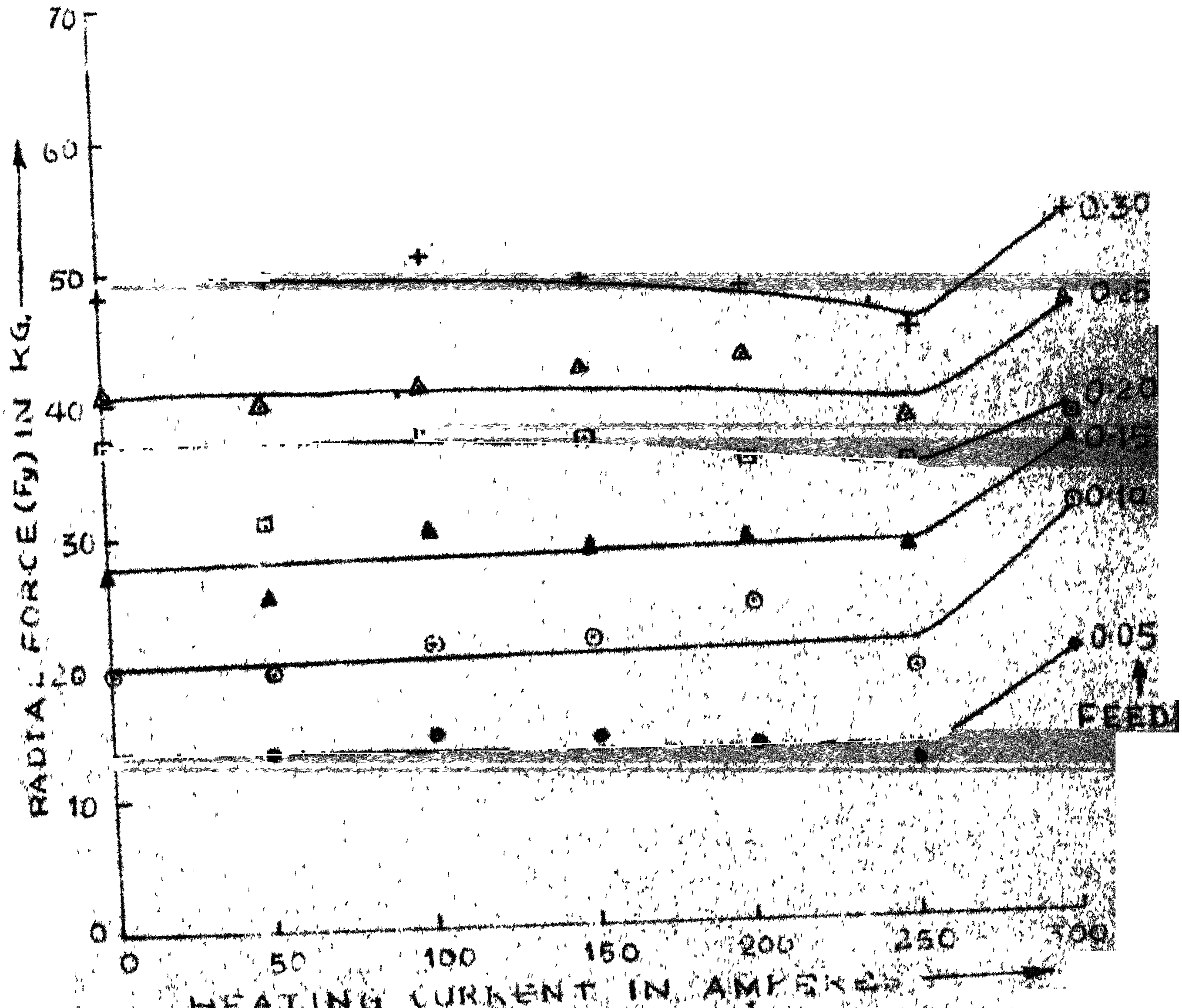
MATERIAL ------ En-24
DEPTH OF CUT --- 1 MM.
CUTTING SPEED -- 22 METERS/MIN.
TOOL -------- THROWAWAY CARBIDE TIP
TOOL GEOMETRY -- [illegible],6,11,11,15,15,1.2 MM.
HEATING ------ ALTERNATING CURRENT



VARIATION OF TANGENTIAL CUTTING FORCE (F_z) WITH HEATING CURRENT FOR DIFFERENT FEEDS

FIGURE NO 23

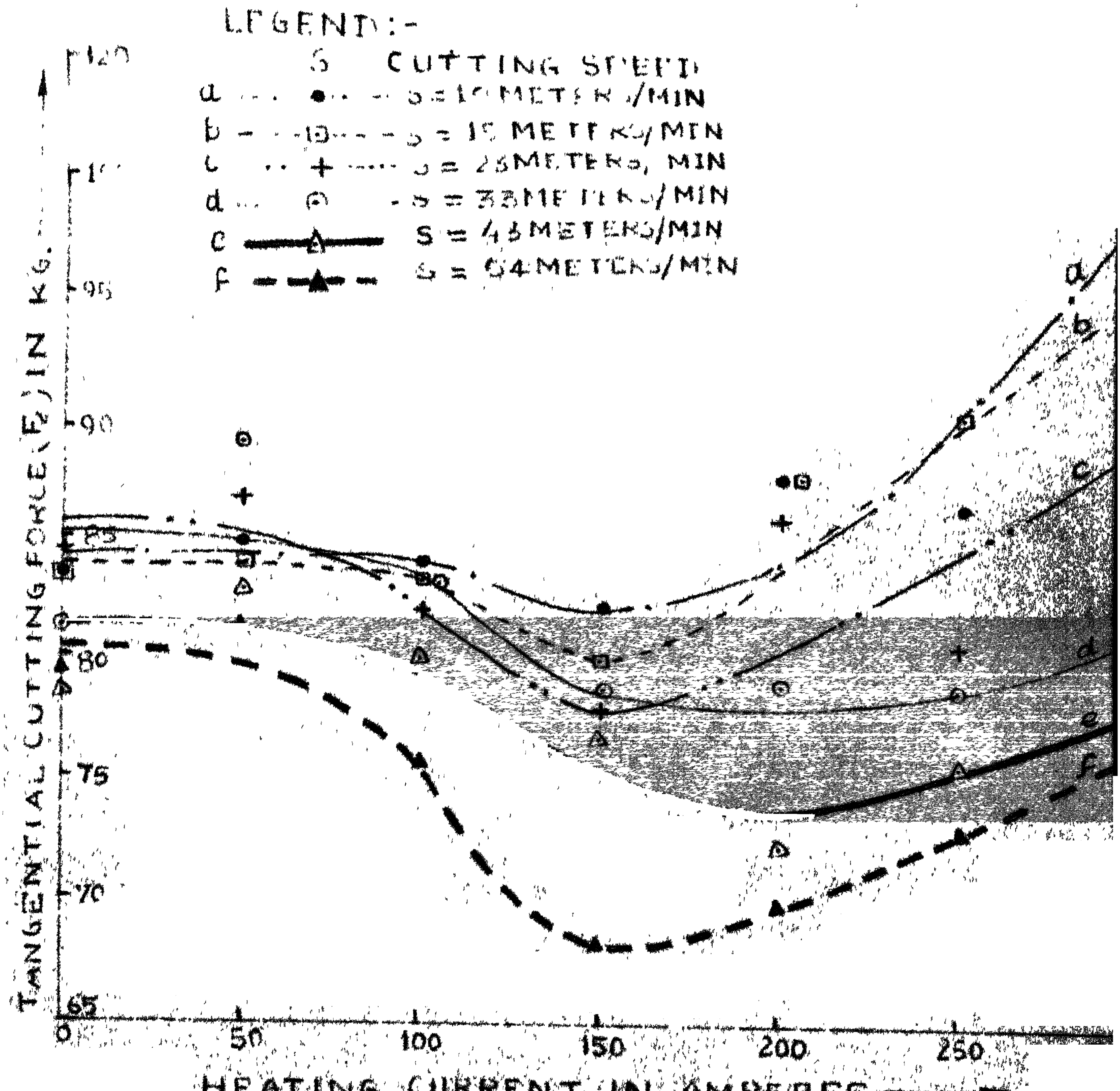
MATERIAL - - - - - - EN 24
DEPTH OF CUT - - 1 MM
CUTTING SPEED - - [illegible] /MIN
TOOL - - - - - - THROW AWAY CARBIDE TIP
TOOL GEOMETRY - 5, 6, 11 11, 15, 15, 1.2 MM
HEATING - - - - - - ALTERNATING CURRENT



VARIATION OF RADIAL FORCE (F_y) WITH HEATING CURRENT FOR DIFFERENT FEEDS

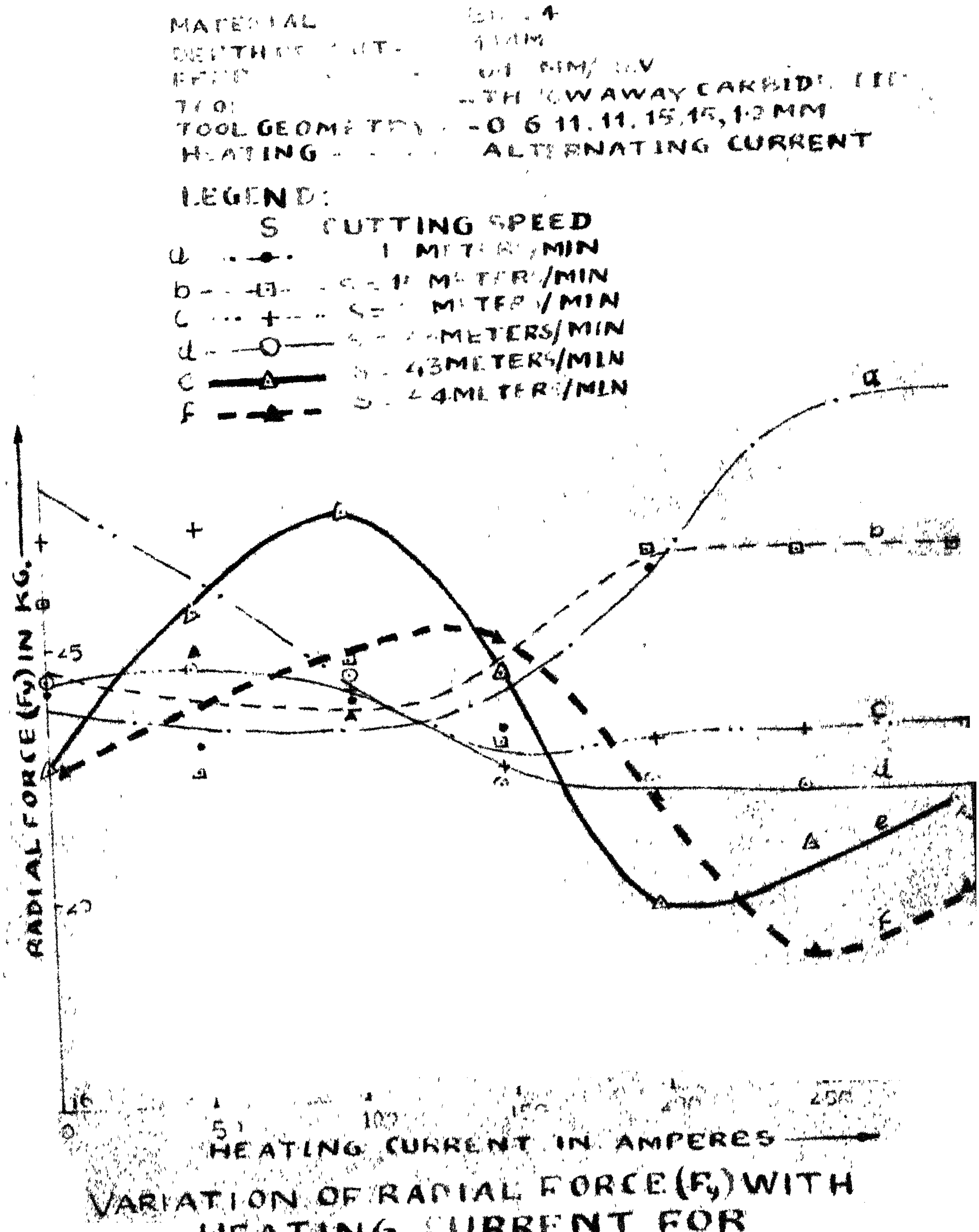
FIGURE NO 24

MATERIAL - - - - - - - EN 24
DEPTH OF CUT - - - 1MM
FEED - - - - - - - - - .15 MM/REV.
TOOL - - - - - - - - THROW AWAY CARBIDE TIP
TOOL GEOMETRY - - 0, 6, 11. 11, 15, 15, 1.2MM.
HEATING - - - - - - ALTERNATING CURRENT



VARIATION OF TANGENTIAL CUTTING FORCE (F_z) WITH HEATING CURRENT FOR DIFFERENT SPEEDS

FIGURE NO 25



VARIATION OF RADIAL FORCE (F_y) WITH HEATING CURRENT FOR DIFFERENT SPEEDS

FIGURE No. 26

wear of the tool at heating current of 300 amperes (Figure 28.7). At feed of 0.2 millimeter/revolution, the tangential cutting force F_z is found to be almost constant with the increase in heating current. Beyond this feed the force F_z drops down with the increase in the current as shown by the curves for the feeds of 0.25 and 0.30 millimeter/revolution.

The total work done per unit volume of metal removed (a) increases with decrease in the feed[26] and (b) decreases with increase in the heating current as a result of reduction in shear stress of the workpiece. If the velocities in the direction of chip-flow, shear and cutting remain constant, the cutting forces in the respective directions will be proportional to the work done. Thus the effect of the heating current on the cutting force F_z at various feeds depends upon the total effect of feed and current on the work done.

Figure 24 shows a graph plotted between radial force F_y along ordinate and heating current along absissa with feed as variable parameter. The force F_y maintains constancy for feed variations in the range of 0.05 to 0.15 millimeter/revolution and heating current variations in the range of 0 to 250 amperes. For increased feeds between 0.2 to 0.3 mm/revolution, the force F_y tends to drop with increase in the current from 0 to 250 amperes.

The reason for the change in the tangential force F_z, as explained earlier, holds good for the change in the radial force F_y also. Sharp change in the magnitude of the force can be observed for all feeds at about 250 amps. This sudden rise in the force F_y can be attributed to excessive tool wear (Figure 28.7). Current range of 200 to 250 amperes is ideally suited for hot machining because the radial force F_y is minimum irrespective of the feed.

3.3.2 Effect of Heating Current on Cutting Forces at Different Speeds:

The plot of the tangential cutting force F_z versus heating current with surface speed as variable parameter is shown in Figure 25. The force F_z decreases as the heating current increases upto 180 amperes. This decrease is found to be appreciable between the range of about 130 to 180 amperes of heating current. Beyond this range tangential cutting force F_z tends to increase as the current increases.

Variation of radial force F_y with the heating current at different speeds are plotted in Figure 26. From the above plot it is revealed that for all the speeds, except at low speeds of 10 and 15 meters/minute, there is an appreciable decrease in the radial force F_y with the heating current in the range of 150 to 250 amperes.

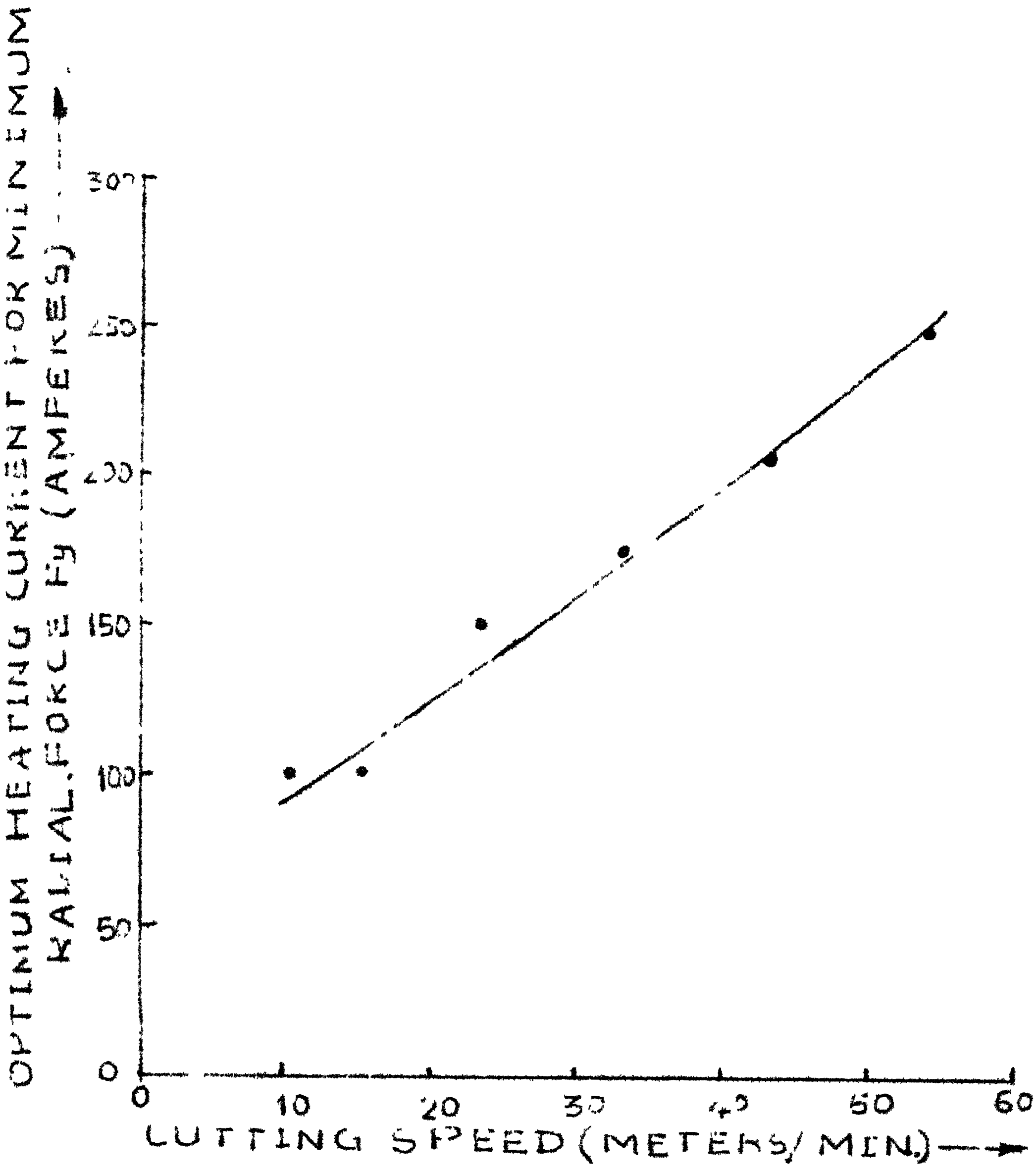
The optimum values of heating currents for minimum radial force F_y are plotted against the cutting speed in Figure 29. In general, it can be said that for all speeds investigated, the optimum value of current lies between 100 to 250 amperes depending upon the cutting speed. This optima increases with increase in cutting speed.

3.3.3 Studies of Chatter Vibration, Chips and Tool Wear:

Amplitude of variation in tangential cutting force F_z is calculated from the force records and plotted against heating current as shown in Figure 30. From the above plot it can be concluded that the vibration is minimum between the range of 150 to 250 amperes of heating current. However, the amplitude of force variation is increased due to excessive chatter caused by large flank wear at 300 amperes (Figure 28.7).

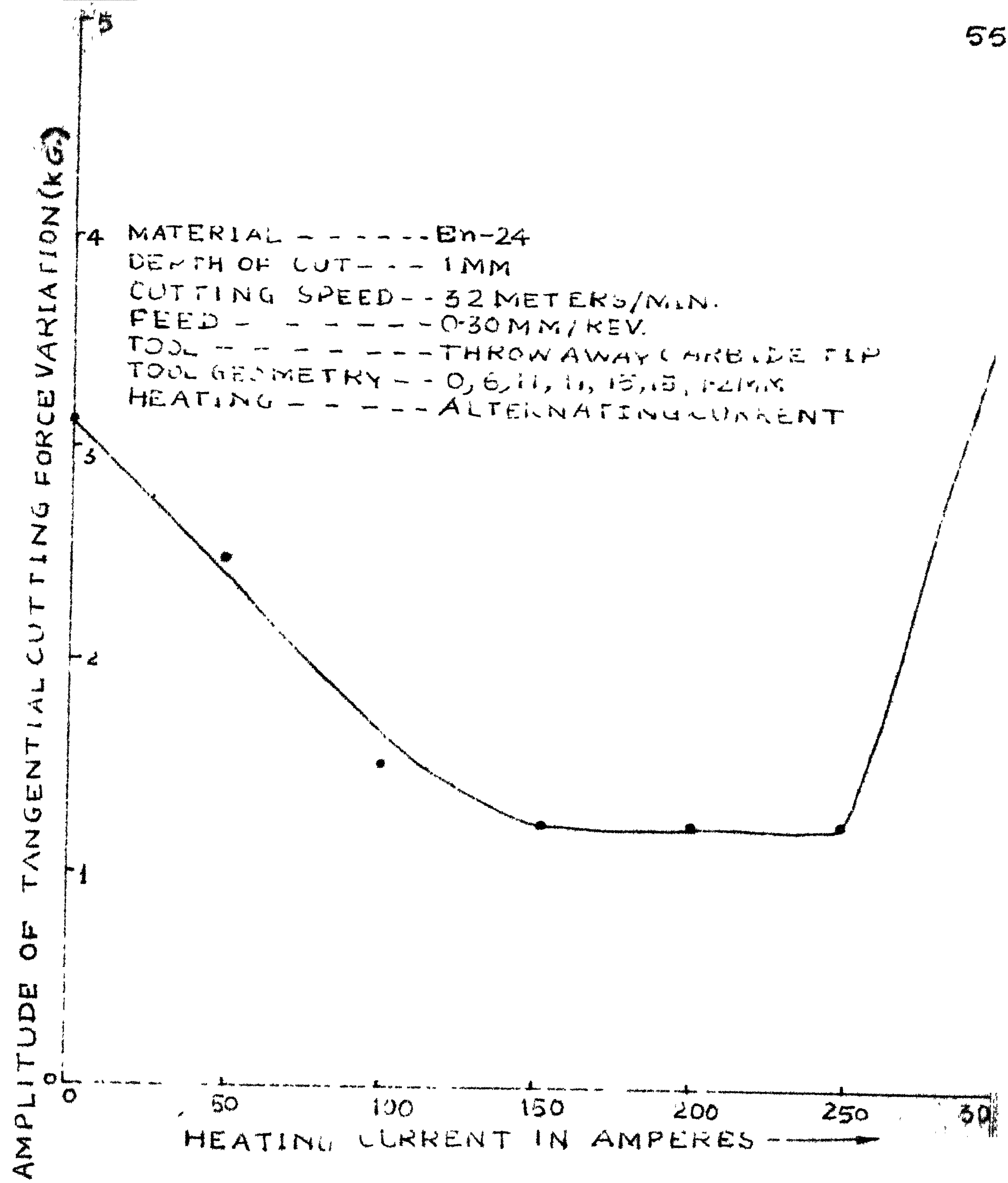
The chip photographs (Figures 27.1 - 27.7) for 0.05 millimeter/revolution feed, 1 millimeter depth of cut and 32 meters/minute cutting speed show that the amplitude of wave on the rough surface of the chips decreases with increase in heating current. These photographs also reveal that with no heating current the chips tend to be discontinuous. With increase in heating current the chips obtained become continuous due to increase in ductility with increase in heating current. So much so that at higher currents (250 and 300 amps.) the chips are in the form of continuous ribbons.

MATERIAL ------- En-24
DEPTH OF CUT ---- 1 MM
FEED ---------- 0·15 MM/REV
TOOL -------- THROWAWAY CARBIDE TIP
TOOL GEOMETRY -- 0, 6, 11, 11, 15, 15, 1·2 MM
HEATING ------ ALTERNATING CURRENT



THE OPTIMUM HEATING CURRENT FOR MINIMUM RADIAL FORCE AT VARIOUS SPEEDS

FIGURE NO 29



AMPLITUDE OF TANGENTIAL CUTTING FORCE(F_z) VARIATION FOR VARIOUS HEATING CURRENT

FIGURE NO 30

The photographs of the tool wear land are shown in Figure 28.1 to 28.7, for heating currents from zero to 300 amperes. These photographs reveal that the tool maintains its shape upto 150 amperes of heating current. Beyond this heating current the flank wear increases as the heating current increases. The tool fails rapidly due to the excessive flank wear at 300 amperes of heating current. The photographs also reveal that the built-up edge exists upto 100 amperes of heating current but disappears at and above 150 amperes of heating current. Disappearance of the built-up edge is also reported by various investigators[8].

Superior surface finish is expected between 100 to 150 amperes of heating currents because of three reasons: (i) the built-up edge disappears between these currents, (ii) there is an increased tendency for formation of continuous chips with increase in current and (iii) chatter vibration is also reduced for the above range of heating currents. Superior surface finish is also reported by previous investigators[2,18].

CHAPTER IV

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

4.1 Conclusions:

The following conclusions are drawn from the present investigation on hot machining:

(i) The heating current in the range of 100 to 150 amps. is found to be optimum as regards to the minimum tangential and radial cutting forces while working at a cutting speed of 32 meters/minute irrespective of the feed.

(ii) At a feed of 0.15 millimeter/revolution and cutting speeds of 10 to 54 meters/minute, 125 to 175 amperes is found to be a suitable range of heating current.

(iii) Chatter vibration is minimum between the heating currents of 150 to 250 amperes.

(iv) The formation of the chip becomes more continuous as the electric current increases.

(v) Tool maintains its shape upto 150 amperes of heating current but beyond this current the flank wear increases and at 300 amperes the tool fails rapidly.

(vi) The built-up edge is not observed at and above 150 amperes of heating current.

(vii) Superior surface finish is predicted while working between 100 to 150 amperes of heating current.

4.2 Suggestions and Scope for Further Work:

Although there are many aspects of hot machining which need investigation, however, the following problems can be investigated on the existing experimental set-up with some modifications:

(i) Judicious instrumentation needs to be introduced for elimination of sparking at the time of engagement and disengagement of the tool from the work-piece while the current is flowing.

(ii) It is suggested to minimise chatter vibration of the tool by reducing its overhang. Chatter may be further reduced by replacing the asbestos insulator with other tougher electrical insulating materials.

(iii) To eliminate errors due to tool wear, it is suggested that the investigation of the cutting forces may be carried out with using a new cutting edge at every change of feed and speed instead of changing the cutting edge at each heating current.

(iv) Implementing the suggestions (ii) and (iii), the set-up can be used to work at speeds higher than the speeds used in the present investigation.

(v) A tool-work thermocouple may be built and incorporated in the present set-up for the study of the cutting temperature during hot machining.

(vi) Tool-life tests during conventional and hot machining can be performed to establish optimum conditions.

(vii) Surface finish measurement during conventional and hot machining can also be carried out using the present set-up.

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APPENDIX I

PROPERTIES OF THE EN-24 STEEL[21]

(1.5% Ni-Cr-Mo Steel)

1. Chemical Composition (%):

C	Si	Mn	S	P	Ni	Cr	Mo
0.35-0.45	0.10-0.35	0.45-0.70	0.050 Max	0.050 Max	1.30-1.80	0.90-1.40	0.20-0.35

2. Mechanical Properties:

		Softened Condition
(i)	Tensile strength tons/sq.in. Min.	50
(ii)	Yield stress tons/sq.in. Min.	38
(iii)	Percentage elongation Min.	20%
(iv)	Brinell hardness	223/277

3. Related Specifications:

U.K.	America	
EN-24	AISI	SAE
	4340	4340

4. Machinability:

The machinability of this steel in the softened condition is approximately 53% of that for mild steel(EN-3).

5. Hot Working and Heat Treatment Temperatures:

Forging, rolling and stamping	1200°C. Finish above. 900°C. Retarded cooling is advisable for large or intricate sections.
Annealing	820°C to 850°C. Furnace cool.
Softening (Sub-critical annealing)	630°C to 660°C. Air or furnace cool.
Hardening	820°C to 850°C. Oil quench.
Tempering for 100 ton condition	180°C to 250°C — Air Cool
For other purposes	550°C to 660°C — Air Cool